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Shipboard Tests of Halon 1301 Test Gas Simulants

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All new and retrofit installations of Halon 1301 total flooding fire protection systems in U.S. Navy shipboard machinery spaces require an acceptance discharge test. The primary reason for this testing is the verification of system design and performance (discharge time, initial concentration, maintenance of concentration, etc.). It is desirable to use a simulant instead of Halon 1301 in these tests in view of its contribution to stratospheric ozone depletion.

Sulfur hexafluoride, SF_6, was identified as a possible simulant on the basis of its similarity to Halon 1301 in physical and chemical properties. A detailed investigation was performed on the use of SF_6 as a simulant, which led to a full scale evaluation on board the USS Chancellorville (CG 62).

This investigation demostrated that based on similarities in concentration profiles, discharge times and leakage characteristics sulfur hexafluoride is an excellant simulant for Halon 1301 in acceptance discharge tests of total flooding fire protection systems, such as used on U.S. Navy ships. (JS)

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CONTENTS

SHIPBOARD TESTS OF HALON 1301 TEST GAS SIMULANTS

1.0 INTRODUCTION.

All new and retrofit installations of total flooding Halon 1301 systems in navy shipboard machinery spaces require a full acceptance discharge test. It is desirable to use a simulant instead of Halon 1301 for these tests in view of current and future regulations on the use of Halon 1301 due to its contribution to stratospheric ozone depletion [1-3].

2.0 BACKGROUND.

2.1 Discharge Tests.

Discharge tests are conducted to verify that the installed Halon 1301 system operates as specified, and was properly designed and installed. There are three primary concerns of these tests. The first concern is that the agent is discharged rapidly in less than the 10 second maximum requirement [4]. The second concern is that a uniform homogeneous mixture with a Halon 1301 concentration equal to or exceeding the design concentration is achieved throughout the protected space. The final concern is that this mixture is maintained in the protected space for the length of time required to ensure complete extinguishment and to allow time to mitigate persistent ignition sources [4] (typically 10 minutes). These and other aspects of discharge testing are

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more fully discussed in a recent review by P.J. DiNenno and E.K. Budnick [5].

2.2 Candidate Simulants.

Two candidate simulants were initially identified by DiNenno et al on the basis of their similarity in physical properties to Halon 1301 [6,7]. The first candidate was sulfur hexafluoride, SF_6, which is primarily used as an insulator in electrical transformers but also has uses as a tracer gas in smoke movement and leak detection and in providing an inert atmosphere for magnesium processing [8,9]. It is colorless, odorless, nontoxic, inert, and is not suspected of contributing to stratospheric ozone depletion [10-12]. Some selected physical properties of SF_6 and Halon 1301 are shown in Table 1 [8,9,13].

The second candidate simulant was chlorodifluoromethane (R-22, Halon 121). It has been primarily used in the refrigeration industry and is viewed as a possible substitute for R-12 (Halon 122, dichlorodifluoromethane) [14]. While it is a chlorofluorocarbon, CFC, it is not considered a stratospheric ozone depleter as it tends to breakdown lower in the atmosphere. It is also included in Table 1 [15,16]. R-22 was first proposed by E.I. du Pont de Nemours & Co. and has been the subject of other studies on simulants for Halon 1301 [17].

Table 1 - Chemical & Physical Properties

	HALON 1301	SULFURHEXAFLOURIDE	R-22
Chemical Formula	$CBrF_3$	SF_6	$CHClF_2$
Molecular Weight	148.93	146.05	86.48
Normal Boiling Point	-57.8°C(-72°F)	-50.8°C(-59.4°F)*	-40.75°C(-41.36°F)
Vapor Pressure at 21°C(70°F)	1.47MPa(213.7psia)	2.16 MPa(312.7psia)	0.94MPa(136.12psia)
Critical Temp	67°C(152.6°F)	45.55°C(114.6°F)	96°C(204.81°F)
Critical Pressure	3.965MPa(575.0psia)	3.759MPa(544.3psia)	4.977MPa(721.91psia)
Liquid Density at 21°C(70°F)	1567kg/m3(97.81lbm/ft^3)	1378kg/m^3(86 lbm/ft^3)	1209kg/m^3(75.51lbm/ft^3)
Vapor Density at 21°C(70°F) and .101MPa(14.7psia)	6.26kg/m^3(0.3911lbm/ft^3)	6.12kg/m^3(.3821lbm/ft^3)	3.64kg/m^3(.2271lbm/ft^3)
Liquid Viscosity at 21°C(70°F)	.00016$\frac{Nsec}{m^2}$(.00013$\frac{lbm}{in\ sec}$)	.00029$\frac{Nsec}{m^2}$(.00023$\frac{lbm}{in\ sec}$)	.0002$\frac{Nsec}{m^2}$(.0016$\frac{lbm}{in\ sec}$)
Vapor Viscosity at 21°C(70°F) and .101MPa(14.7psia)	.000016$\frac{Nsec}{m^2}$(.00013$\frac{lbm}{in\ sec}$)	.000015$\frac{Nsec}{m^2}$(.00012$\frac{lbm}{in\ sec}$)	.000013$\frac{Nsec}{m^2}$(.00010$\frac{lbm}{in\ sec}$)
Thermal Conductivity of Vapor at 21°C(70°F) + .101MPa(14.7psia) air .0255W/m°K(.0147$\frac{Btu}{hrft°F}$)	.0092W/m°K(.0053$\frac{Btu}{hrft°F}$)	.0142W/m°K(.0082$\frac{Btu}{hrft°F}$)	.0105W/m°K(.006$\frac{Btu}{hrft°F}$)
Enthalpy of Vaporization at Boiling Point	17,700$\frac{kJ}{kgmole}$(7,607$\frac{Btu}{lbmole}$)	18,840$\frac{kJ}{kgmole}$(8,100 $\frac{Btu}{lbmole}$)*	20,220$\frac{kJ}{kgmole}$(8,693$\frac{Btu}{lbmole}$)
at 21°C(70°F)	12,310$\frac{kJ}{kgmole}$(5,292$\frac{Btu}{lbmole}$)	9,630$\frac{kJ}{kgmole}$(4,140$\frac{Btu}{lbmole}$)	16,160$\frac{kJ}{kgmole}$(6,948$\frac{Btu}{lbmole}$)

*Triple Point 0.224 MPa -50.8°C (32.5psia -59.4°F)

3.0 SMALL SCALE TESTS.

Three series of tests were previously conducted at the Chesapeake Bay Detachment of the Naval Research Laboratory [6,7,18,19]. These tests evaluated both candidate simulants on the basis of leakage from an enclosure, the initial mixing with air, discharge times and distribution between nozzles.

3.1 Leakage Tests.

The first series of tests were aimed at the leakage from an enclosure [6,7]. In these tests a 43 m^3 (1519 ft^3) enclosure, 3.66 m (12 ft) tall, was flooded with either Halon 1301 or one of the two candidate simulants with a resulting concentration of 5% by volume. The mixture was then allowed to leak through an opening in the enclosure of a known size while the height of the interface between the mixture and air was recorded. A second opening of the same size was provided near the ceiling of the enclosure to allow make-up air to enter the enclosure.

The sulfur hexafluoride-air mixture was found to leak at a rate similar to that of the Halon 1301-air mixture for each of the three leak sizes used. The length of time required for the SF_6-air interface to descend was always within 10% of that required for the Halon 1301-air interface.

The R-22-air mixture was found to leak at a slower rate. It took nearly 50% longer for the R-22-air interface to descend.

3.2 Initial Mixing Tests.

The second series of tests was aimed at the initial mixing with air upon discharge into an enclosure [18]. In these tests, the nozzle of the total flooding system was obstructed with a baffled rectangular tube. The amount of Halon 1301 or of the two candidate simulants that would have resulted in the same percent by volume mixture in an unobstructed test was used. The resulting concentration profile for Halon 1301 or the two candidate simulant was recorded.

The resulting concentration profiles for both candidate simulants and Halon 1301 were found to be similar.

3.3 Discharge System Tests.

The third series of tests was aimed at the discharge rate and distribution between nozzles [19]. This series was divided into two parts; modular system flows and banked system flows. The modular system used the same 13.6 kg (30 lb) Fenwal storage cylinder superpressurized to 2.48 MPag (360 psig) and BETE spiral nozzle that was used in the two previous test series. The fill density of Halon 1301 was varied with the amount of the two candidate simulants being that required to achieve the same percent by volume concentration.

In the second part of this series, U.S. Navy hardware was used. This included a 56.7 kg (125 lb) Ansul storage cylinder superpressurized to 4.1 MPag (600 psig) and the standard 360° four hole nozzles. Six different discharge systems were utilized in these tests. They ranged in complexity from a balanced two nozzle system to a four nozzle system with three unbalanced tees (not a 50-50 flow split at the tee).

In both parts of these tests, sulfur hexafluoride was found to discharge at a rate similar to that of Halon 1301. The discharge time for SF_6 was within 11% of that for Halon 1301 for all the systems tested. R-22, on the other hand, was found to discharge at a faster rate. Its discharge time was as much as 40% shorter.

The distribution of flow between nozzles was similar for both candidate simulants and Halon 1301.

4.0 SHIPBOARD TOTAL FLOODING HALON 1301 SYSTEM TESTS.

4.1 Objective.

The purpose of these tests was to further evaluate sulfur hexafluoride, SF_6, as a simulant for Halon 1301 in shipboard total flooding discharge tests. This evaluation was based on the similarity in piping, nozzle, mixing, and leakage characteristics.

4.2 Test Facilities.

These test were conducted onboard a new guided missile cruiser, the USS Chancellorsville (CG-62), undergoing its certification and delivery procedures at Ingalls Shipyard in Pascagoula Mississippi. Engine room number 2 was utilized and is shown in Figures 1 and 2. This room spans 4 deck

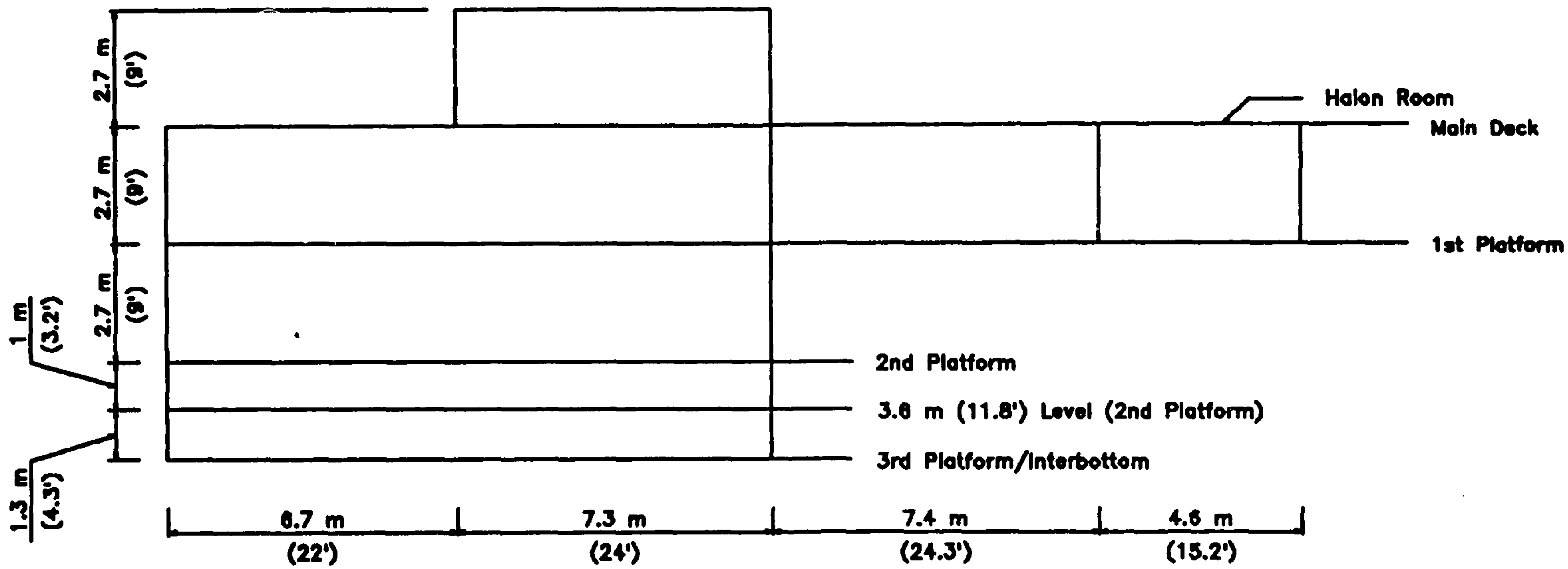

Fig. 1 – Elevation view of engine room no. 2

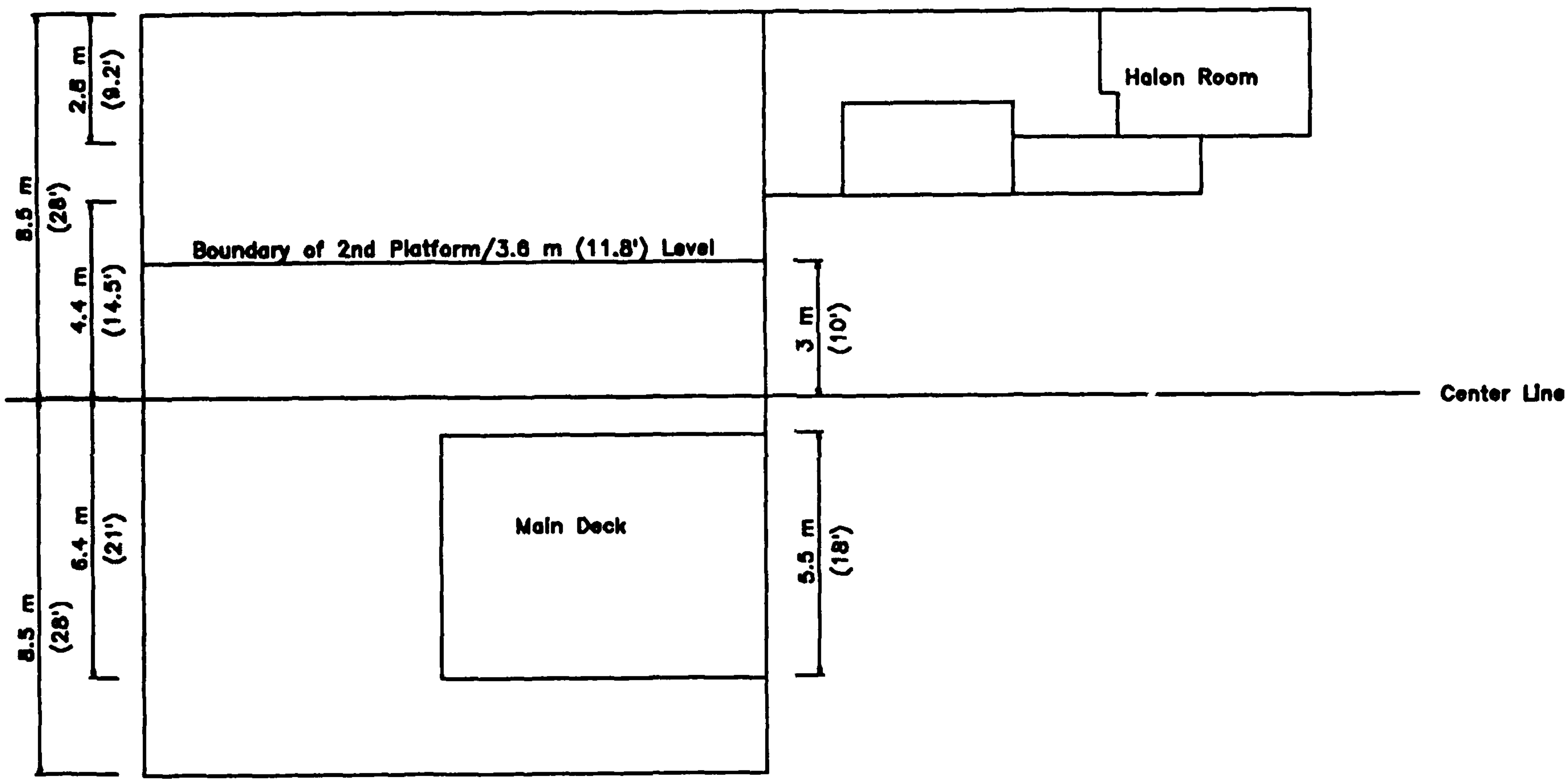

Fig. 2 — Plan view of engine room no. 2

levels between water tight bulkheads 300 and 346 and has a volume of approximately 1870 m^3 (66,000 ft^3) [20]. The local control center on the 1st platform is separated from the rest of the space by solid boundaries with only limited access (through an open hatch, an open doorway or the escape trunk). The four decks consist of grating around machinery with the exception of half of the 1st platform (local control center) and a portion of the 2nd platform which have solid decks.

The Halon 1301 total flooding system installed to protect engine room number 2 was utilized. This system has 20 nozzles distributed throughout the engine room as shown in Figures 3 through 6 [21]. It has a central bank of Halon 1301 cylinders with both a primary and reserve capacity. This bank consists of 22 cylinders, each rated for 56.7 kg (125 lb) of Halon 1301 and superpressurized with nitrogen to 4.1 MPag (600 psig). Three other spaces are protected with Halon 1301 from this bank; engine room number 1, and auxiliary machine rooms number 1 and 2. Four stop valves are used to direct the flow of Halon 1301 to the correct space. This system is pneumatically controlled with carbon dioxide cylinders providing the pressure pulse required to actuate the system. The control system, in addition to cylinder actuation and flow direction, activates predischarge alarms, shuts down ventilation fans, provides a nominal 60 second time delay, and activates discharge alarms.

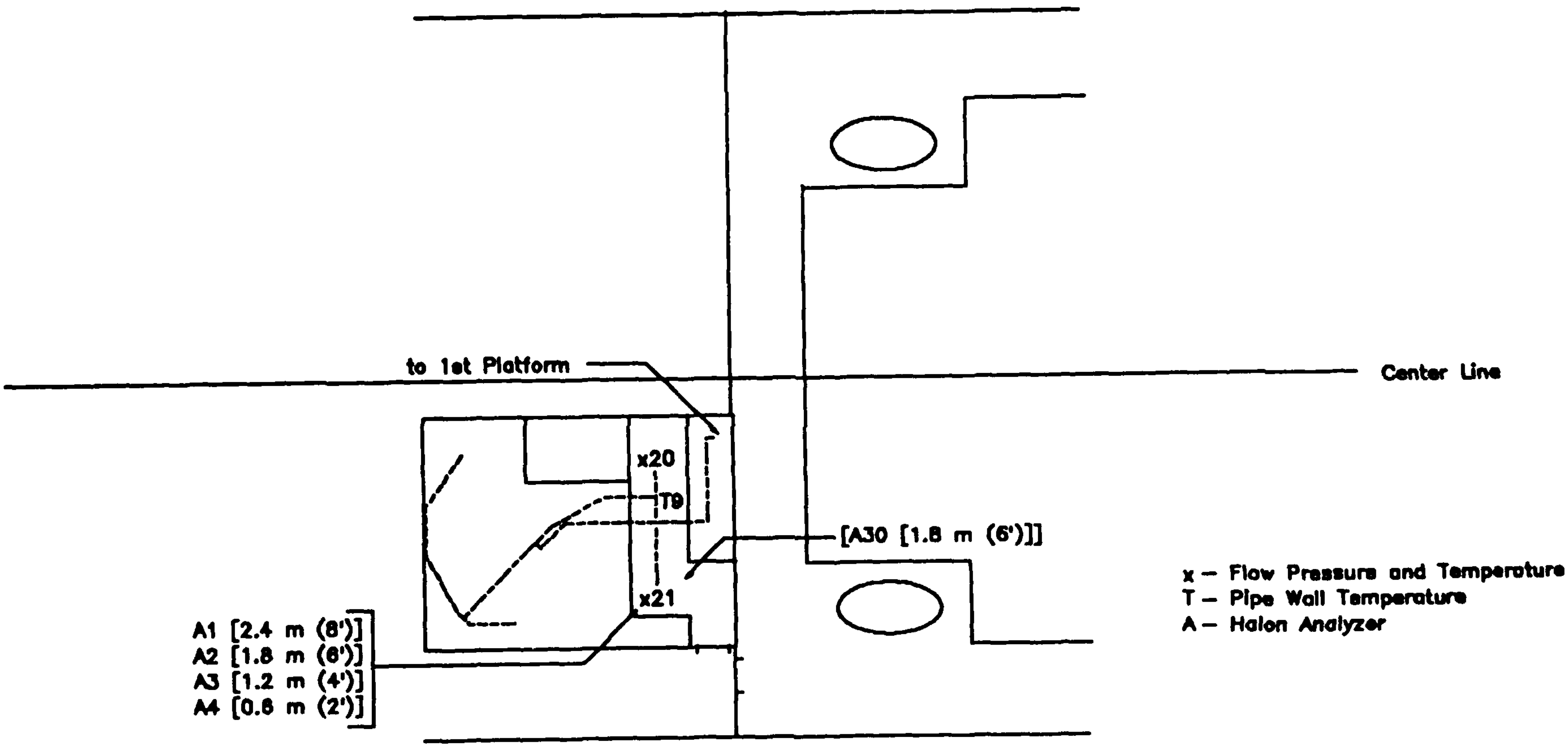

Fig. 3 — Main deck plan of engine room no. 2 and passageways

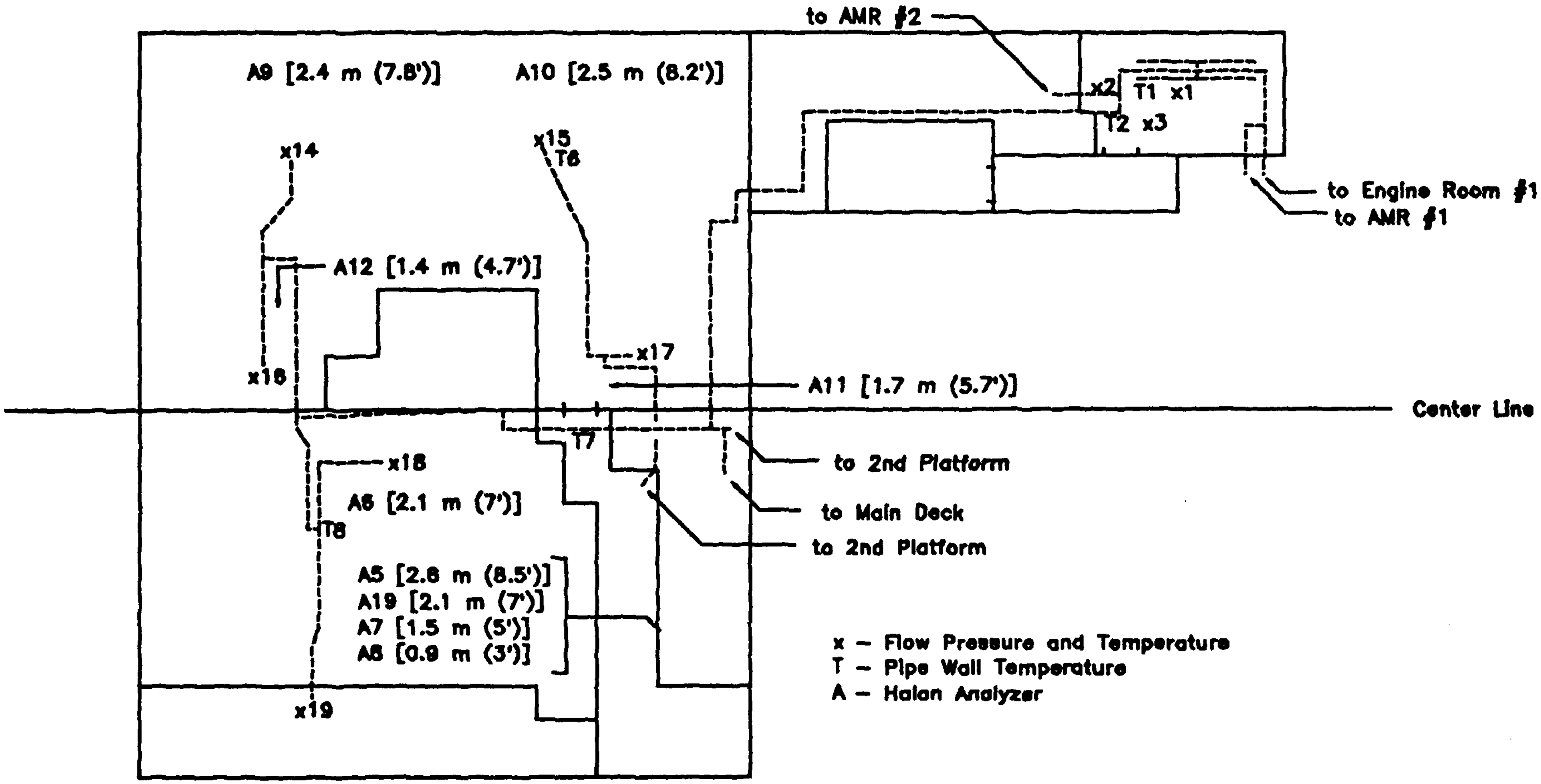

Fig. 4 – 1st platform plan of engine room no. 2

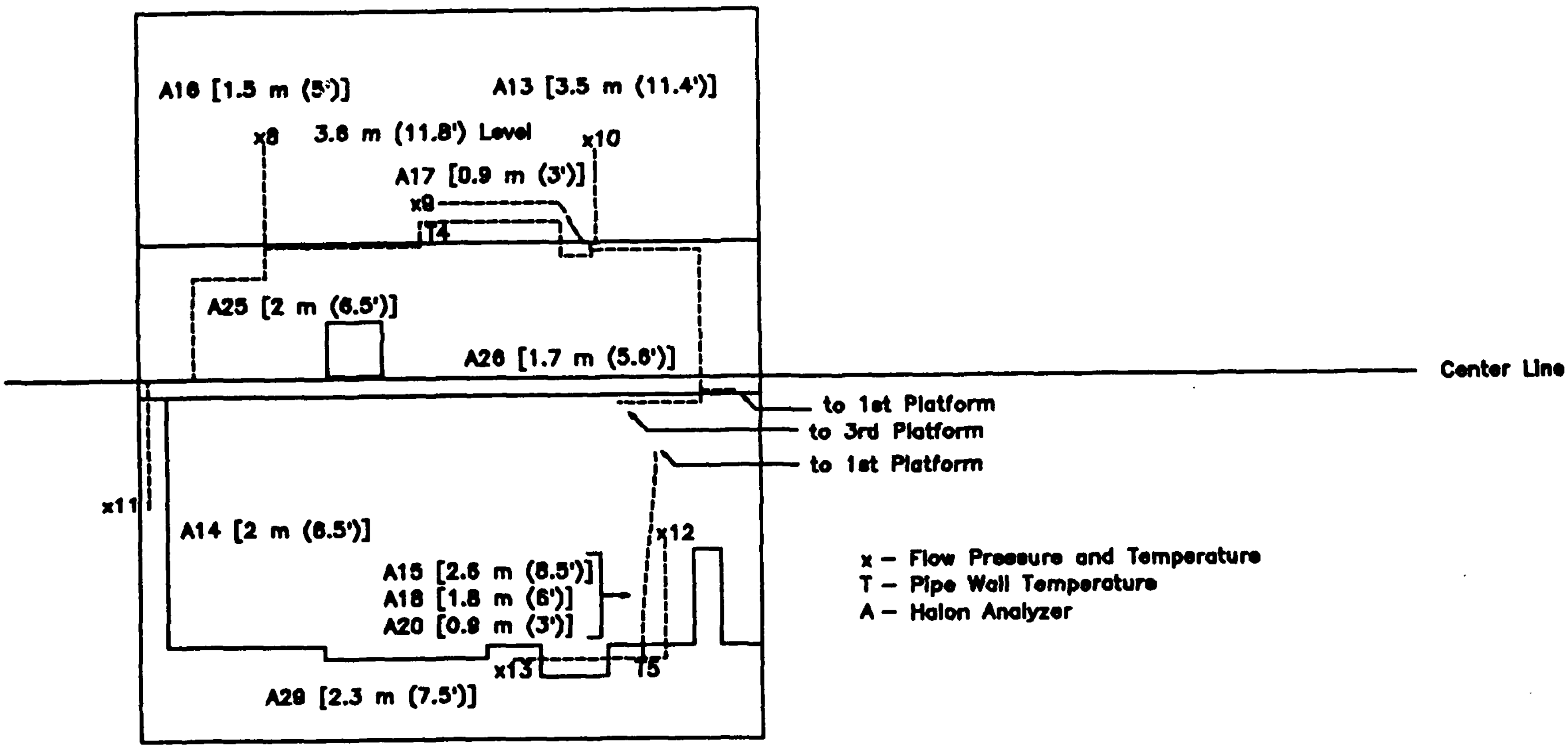

Fig. 5 – 2nd platform plan of engine room no. 2

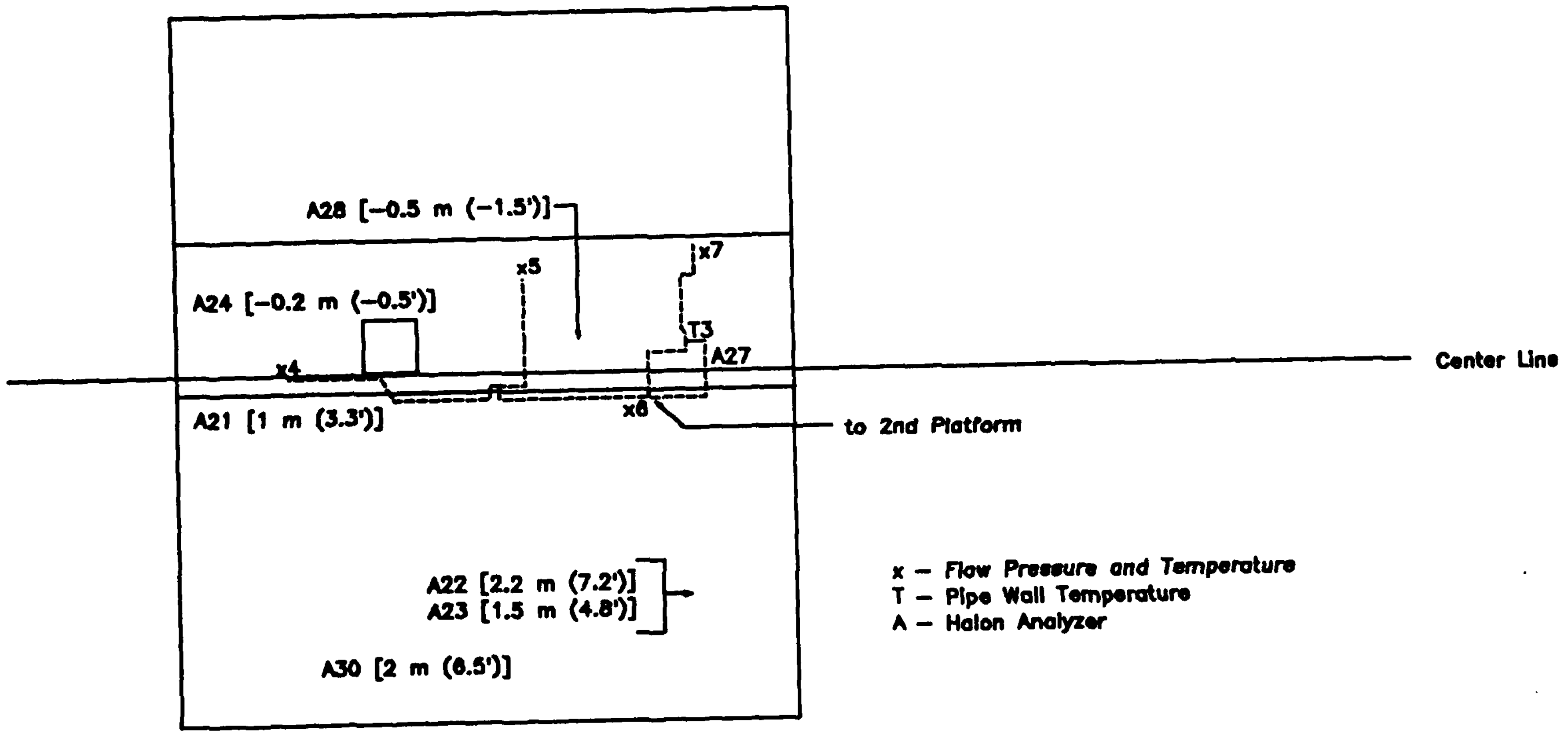

Fig. 6 – Interbottom/3rd platform plan of engine room no. 2

The discharge system parameters are similar to those used in the previous tests on discharge systems [19]. The fill density of the cylinders is 1100 kg/m^3 (70 lb/ft^3) [22]. The percent agent in the pipe network is approximately 40 % and the pressure drop in the network is approximately 1 MPag (145 psig) [22].

The pneumatic time delay device was removed and its connections were plugged for these tests. This was done to allow manual control of the cylinder actuation through the time delay bypass valve.

This system was chosen because of the large volume of the protected space, the high number of obstructions, and the complexity of the system. CG-47 class ships, of which CG-62 is one, carry the U.S. Navy's most complex total flooding Halon 1301 system.

4.3 Procedure.

Discharge tests were conducted for both Halon 1301 and sulfur hexafluoride with the same average percent by volume concentration.

<u>4.3.1 Test Sequence.</u>

A. Install cylinders charged with the desired agent, 56.7 kg (125 lb) of Halon 1301 or 54.9 kg (121 lb) of SF_6, and superpressurized to 4.1 MPag (600 psig) with nitrogen.

B. Actuate Halon 1301 system.

C. Initiate computer data logging 50 seconds after system actuation.

D. Hit time delay bypass to actuate cylinders 60 seconds after system actuation.

E. Restart ventilation system 2 hours after the discharged of agent has ended.

F. Test is ended when space is free of agent.

4.4 Instrumentation.

The location of instrumentation in ER #2 and the Halon Room is shown in Figures 3 through 6.

4.4.1 Halon 1301 Analyzers.

Halon 1301 and sulfur hexafluoride concentrations were monitored by twelve thermal conductivity analyzers (seven Perco Halon Analyzers and five Tuure Halon Analyzers). Each of these provide three sampling points for a total of 36 sampling points. All analyzers were located remotely from the space with .16 cm (.25 in.) Tygon tubing, 30.5 m (100 ft) in length, transiting to the desired sampling point. Thirteen of these sampling points were placed in a vertical tree in order to obtain the vertical concentration profile at a single location. The top seven of these points were placed on 0.61 m (2 ft) intervals starting 0.3 m (1 ft) from the 01 Deck (1 deck above Main). The remaining six were placed with 0.91 m (3 ft) intervals. Seventeen other points were located in the engine room to monitor the concentration at various locations. The thirty sampling point locations in the engine room are shown in Figures 3 through 6 with the elevation of the point above the deck or platform level in brackets. Note that point 30 was moved in between tests with the location in brackets being its location for the SF_6 test.

Six points were used to monitor the flow of Halon 1301 or SF_6 in the ventilation ducts; three in the intake trunk and three in the exhaust plenum. The three in the intake trunk were placed on the louvered intake to the fan room. The three in the exhaust plenum were placed as follows:

- One point located 2.1 m (6.8 ft) above the 01 Deck between the two ventilation exhaust fans,
- One point located 0.61 m (2 ft) above the exhaust fans, and
- One point located near the louvered exhaust to the weather near the 03 deck (5.5 m (18 ft) above the 01 deck).

4.4.2 Fluid Pressure.

The pressure of the flowing Halon 1301 or SF_6 was monitored with 21 pressure transducers (13 Genisco Technology Corporation model SP500 pressure transducers with a range of 0-6.9 MPag (0-1000 psig), 5 Omega Engineering model PX-303 pressure transducers with a range of 0-6.9 MPag (0-1000 psig), and 3 Viatran Corporation model 118C82 pressure transducers, two with a range of 0-5.2 MPag (0-750 psig) and one with a range of 0-1.4 MPag (0-200 psig). The location of these transducers are shown in Figures 3 through 6 and had the following breakdown:

A. 1 pressure transducer located at the check valve at the entrance to the manifold.

B. 1 pressure transducer located in the manifold before the stop valve to Engine Room #2 (stop valve leading to Auxiliary Machine Room #2 was removed to accomplish this).

C. 1 pressure transducer located after the stop valve at the air hose connection.

D. 18 pressure transducers located at nozzles (all but 2 of the 4 nozzles located on the main deck).

4.4.3 Thermocouples.

The temperature of the flowing fluid was monitored by 21 Inconel sheathed type K (chromel-alumel) thermocouples 0.159 cm (0.063 in.) in diameter. These thermocouples were placed at the same locations as the pressure transducers used to monitor fluid pressure.

Nine glass braid type K thermocouples were used to monitor the temperature of the pipe walls. The location of these are shown in Figures 3 through 6.

4.4.4 Compartment Pressure.

A Schaevitz Engineering model 3091 pressure transducer with a range of 0-500 Pa (0-2 in. H_2O) was used to measure the pressure pulses in the engineer room during the discharge of agent. This transducer was located at the ceiling of the first platform at a cable penetration that passed through the main deck to the passageway outside the entrance to the engine room.

4.4.5 Anemometers.

A three point 0-5000 SFPM Kurz Instruments model EVA-4000 hot wire anemometer was mounted above one of the two ventilation exhaust fans. This was done to measure the flows through the ventilation exhaust duct caused by the coast down of the fan, the discharge and the wind.

A vane type anemometer was used to measure wind speed and direction during the test.

4.5 Results.

The concentration of both Halon 1301 and sulfur hexafluoride obtained at each sampling point over the duration of these tests is given in Table 2. The maximum difference in concentration is 2.4 percent by volume at sampling point number 24, one hour after discharge. This is a relative difference of 27%. The average relative difference between the concentrations of SF_6 and Halon 1301 was 7.4% while the relative difference in average concentrations was 3.9%. The weight record of each cylinder revealed that both the SF_6 and Halon 1301 cylinders were charged to the same mass of agent which would result in a 3.1% higher average concentration of SF_6. After this correction is applied, the relative difference in average concentrations is 0.8%.

Table 2 - Concentrations of Halon 1301 and sulfur hexafluoride

POINT	1 MIN		5 MIN		10 MIN		15 MIN		60 MIN		110 MIN	
	HALON	SF6	HALON	SF6	HALON	SF6	HALON	SF6	HALON	SF6	HALON	SF6
A1	4.2	5.1	3.5	3.5	2.5	1.9	2.5	1.9	3.0	2.7	2.6	2.5
A2	3.9	4.0	3.9	3.6	3.6	3.3	3.5	3.2	3.0	2.7	2.6	2.4
A3	4.4	4.5	4.5	4.5	4.3	4.4	4.2	4.3	3.2	3.0	2.9	2.7
A4	4.4	4.2	4.2	3.9	4.1	3.9	4.0	4.0	4.1	4.1	4.1	4.1
A5	4.6	4.3	4.3	4.1	4.1	4.0	4.2	4.0	4.1	4.2	4.0	4.5
A6	5.2	5.1	5.1	4.8	4.9	4.8	4.8	4.7	4.4	4.3	4.3	4.4
A7	5.0	5.1	5.4	4.9	5.3	4.9	5.4	4.9	5.2	4.8	5.1	4.6
A8	5.3	5.5	5.7	5.4	5.7	5.4	5.6	5.3	5.2	5.0	5.5	4.6
A9	5.9	6.6	5.0	5.0	4.8	5.0	4.8	4.9	4.6	4.9	4.5	5.2
A10	4.7	4.2	4.4	4.2	4.1	4.1	4.1	4.1	4.1	4.3	4.1	4.6
A11	5.3	6.2	5.0	5.0	4.9	5.0	4.8	5.0	5.1	5.1	5.0	5.0
A12	6.6	7.8	5.6	5.5	5.7	5.4	5.7	5.4	5.4	5.4	5.3	5.1
A13	3.5	3.3	5.2	4.9	5.7	5.5	5.8	5.8	6.2	6.2	6.0	6.0
A14	6.3	5.9	6.6	6.7	6.6	6.6	6.6	6.7	6.4	6.6	6.3	6.4
A15	6.2	5.9	6.6	6.5	6.6	6.5	6.6	6.6	6.5	6.7	6.4	6.5
A16	7.0	6.8	7.5	7.6	7.4	7.5	7.3	7.5	7.1	7.3	6.7	7.1
A17	7.1	7.8	7.1	7.9	7.0	8.0	6.9	7.9	6.6	7.3	6.6	7.6
A18	>10	13.5	>10	14.0	>10	14.0	>10	14.2	>10	14.0	>10	13.7
A19	7.0	7.5	6.8	7.3	6.5	7.1	6.5	7.2	5.6	7.0	5.8	7.3
A20	9.3	11.0	9.6	11.5	9.5	11.2	9.3	11.1	9.0	10.1	8.7	10.1
A21	8.6	9.9	9.0	10.0	8.9	10.0	8.8	10.0	8.6	9.3	8.5	8.9
A22	8.3	8.3	8.8	9.0	8.8	9.2	8.7	9.2	8.0	7.4	7.6	7.1
A23	>10	12.1	>10	12.7	>10	13.0	>10	13.0	9.5	10.5	9.3	10.4
A24	8.5	6.9	9.0	7.1	9.1	6.9	9.0	6.7	8.8	6.4	8.3	6.4
A25	6.9	7.7	8.0	8.8	8.1	8.8	8.0	8.7	7.7	8.3	7.5	8.3
A26	7.8	9.1	9.1	9.4	9.4	9.4	9.4	9.3	8.9	8.8	8.7	8.4
A27	>10	16.7	>10	16.8	>10	16.8	>10	16.6	>10	16.6	>10	16.4
A28	8.9	10.4	8.8	10.3	8.7	10.2	8.7	10.3	8.1	9.8	7.9	9.2
A29	7.6	6.7	8.9	7.6	8.9	7.8	8.9	7.9	8.6	7.9	8.4	7.6
A30*	7.5	5.1	8.4	4.5	8.1	3.7	8.0	3.5	7.3	2.7	6.4	2.6
AS1	2.1	2.6	0.6	0.6	0.0	0.3	0.0	0.3	0.1	0.2	0.2	0.3
AS2	1.5	1.5	0.4	1.0	0.1	0.5	0.0	0.5	0.2	0.6	0.2	0.4
AS3	1.4	1.4	0.2	0.4	0.1	0.4	0.1	0.4	0.1	0.3	0.3	0.6
AE1	4.1	4.7	2.4	2.5	0.8	1.1	0.7	0.9	0.6	1.1	0.3	-
AE2	3.7	5.3	1.8	1.9	0.5	0.5	0.4	0.5	0.1	0.3	0.2	0.3
AE3	0.1	0.3	0.0	0.1	0.0	0.2	0.0	0.2	0.1	0.2	0.1	0.1

* Point 30 was moved inbetween tests

The concentration traces of both SF_6 and Halon 1301 at 4 representative points over the duration of the two tests are shown in Figures 7 through 10. These figures graphically illustrate how well SF_6 simulates Halon 1301 over the duration of tests. The concentration traces at the remaining points are given in Appendix A.

The vertical concentration profiles for both SF_6 and Halon 1301 over the duration of the tests are shown in Figures 11 through 16. The profiles for both are similar.

The discharge time was 13 seconds for both Halon 1301 and SF_6 as determined from the temperature and pressure traces. The inflection in these traces that represents the liquid run out point was taken as the discharge time.

The relationships in temperature and pressure between nozzles (ie. temperature at nozzle x20 is less than that at nozzle x7) in both the Halon 1301 test and the SF_6 are similar as shown in Figures 17 through 20 for representative nozzles. This implies that the distribution of agent between nozzles is also similar for both agents. In general, the pressures for SF_6 are higher than for Halon 1301 and the temperatures are lower for SF_6. The temperature and pressure traces for other nozzles are given in Appendix A.

These same relationships are reflected in the external pipe wall temperatures for SF_6 and Halon 1301 as shown in Figures 21 and 22 for representative locations. The temperatures for SF_6 are lower than those for Halon 1301 and

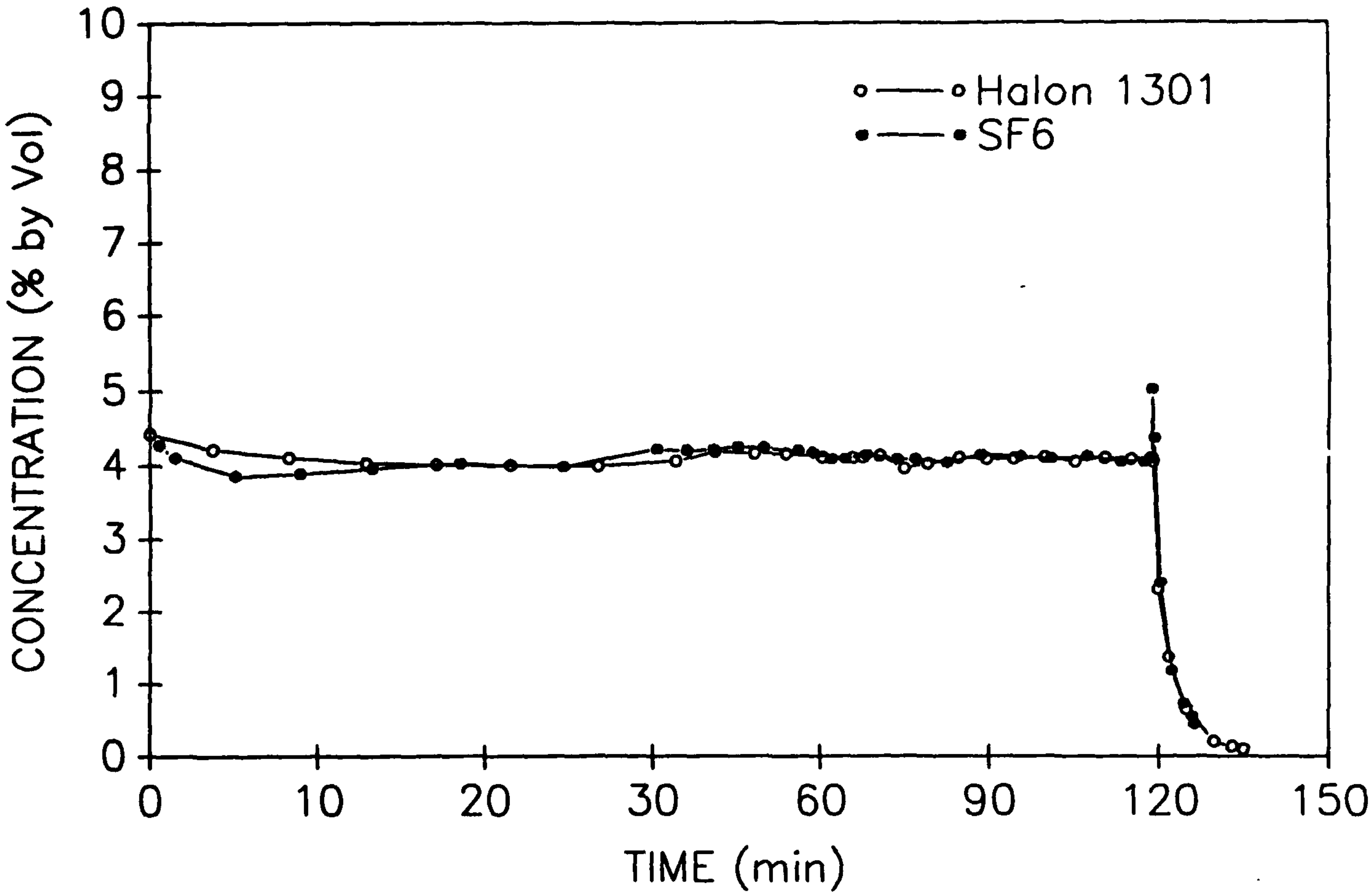

Fig. 7 – Concentration at Analyzer Point 4

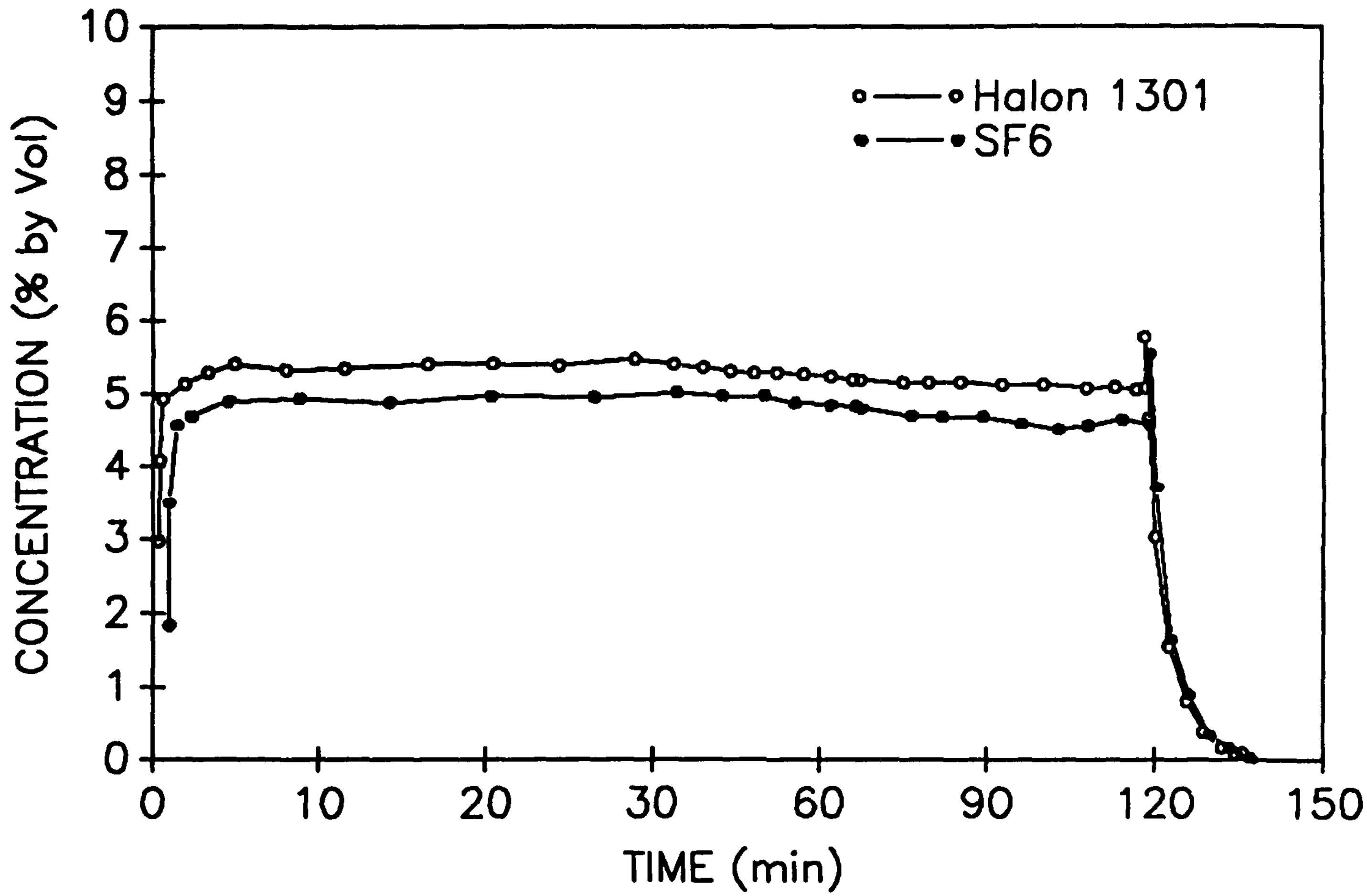

Fig. 8 — Concentration at Analyzer Point 7

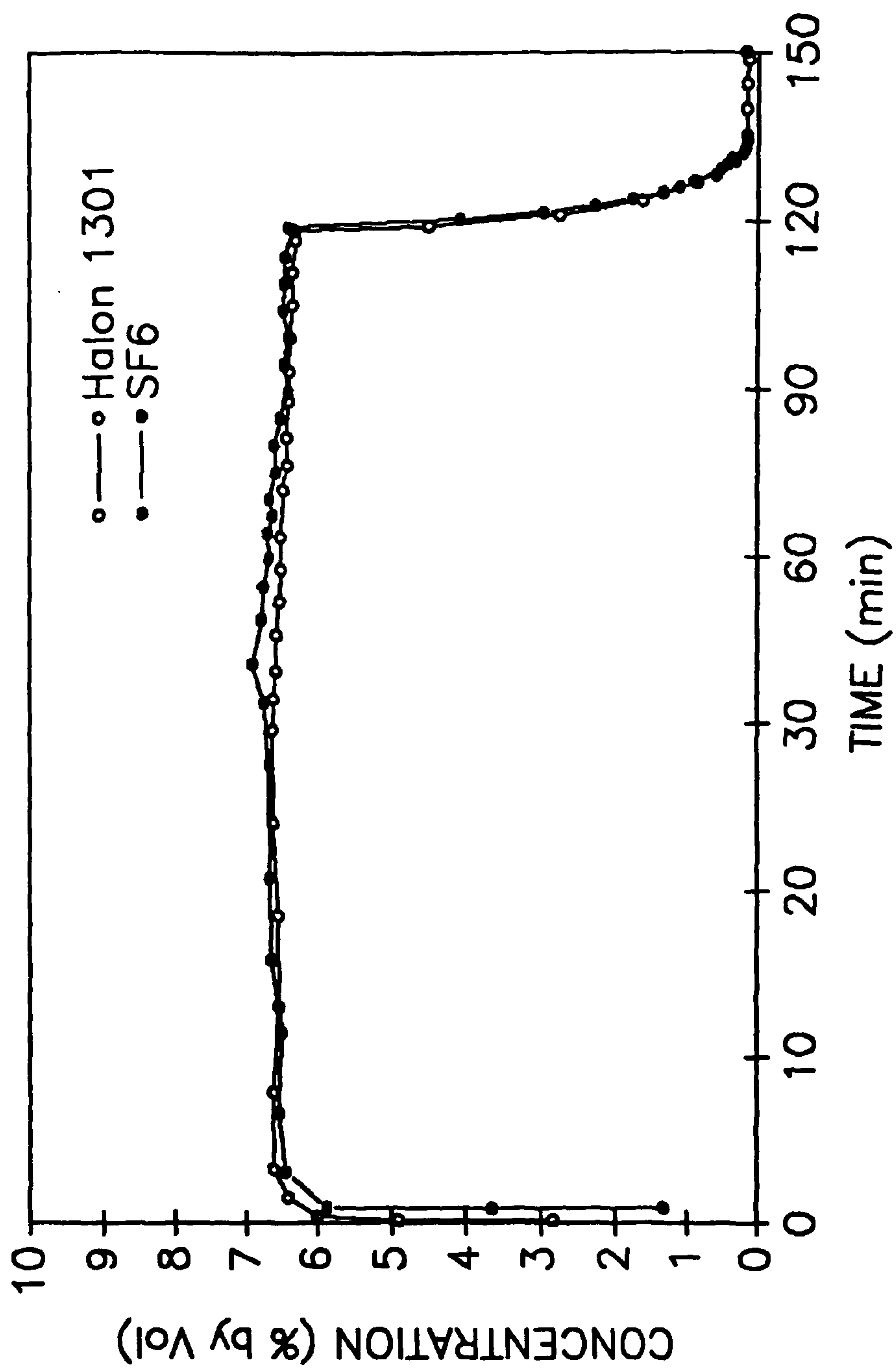

Fig. 9 — Concentration at Analyzer Point 15

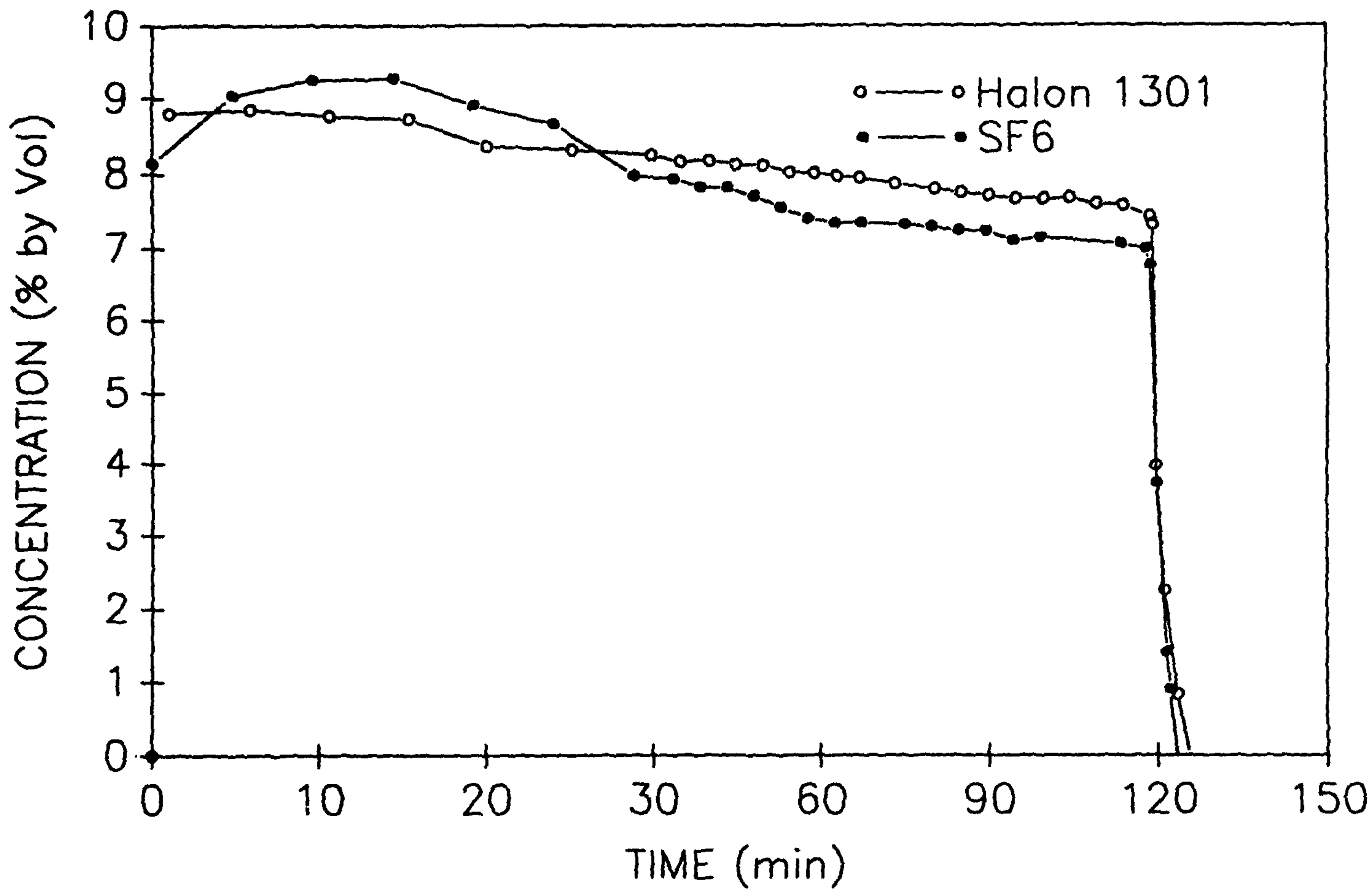

Fig. 10 – Concentration at Analyzer Point 22

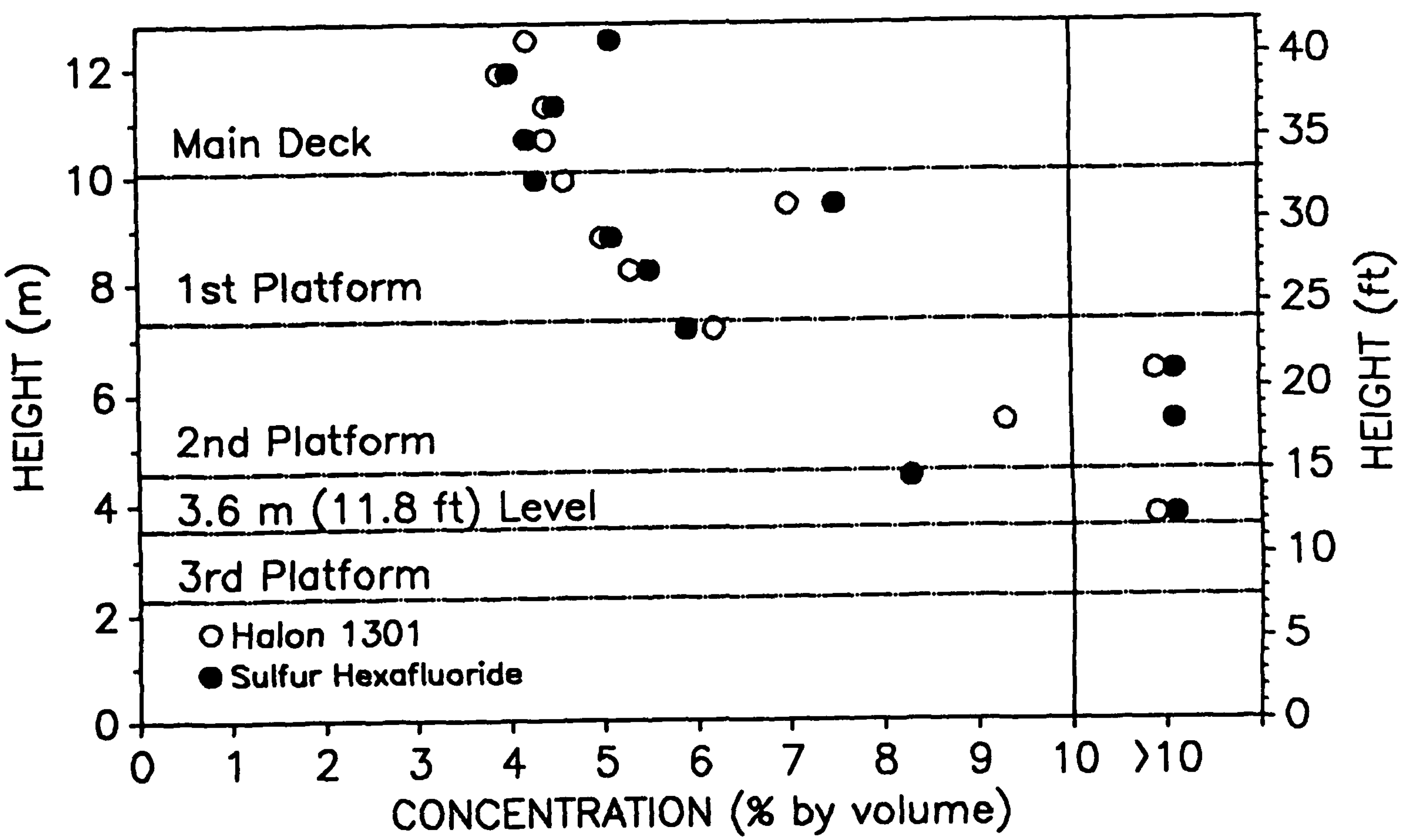

Fig. 11 — Vertical concentration profile
1 minute after discharge

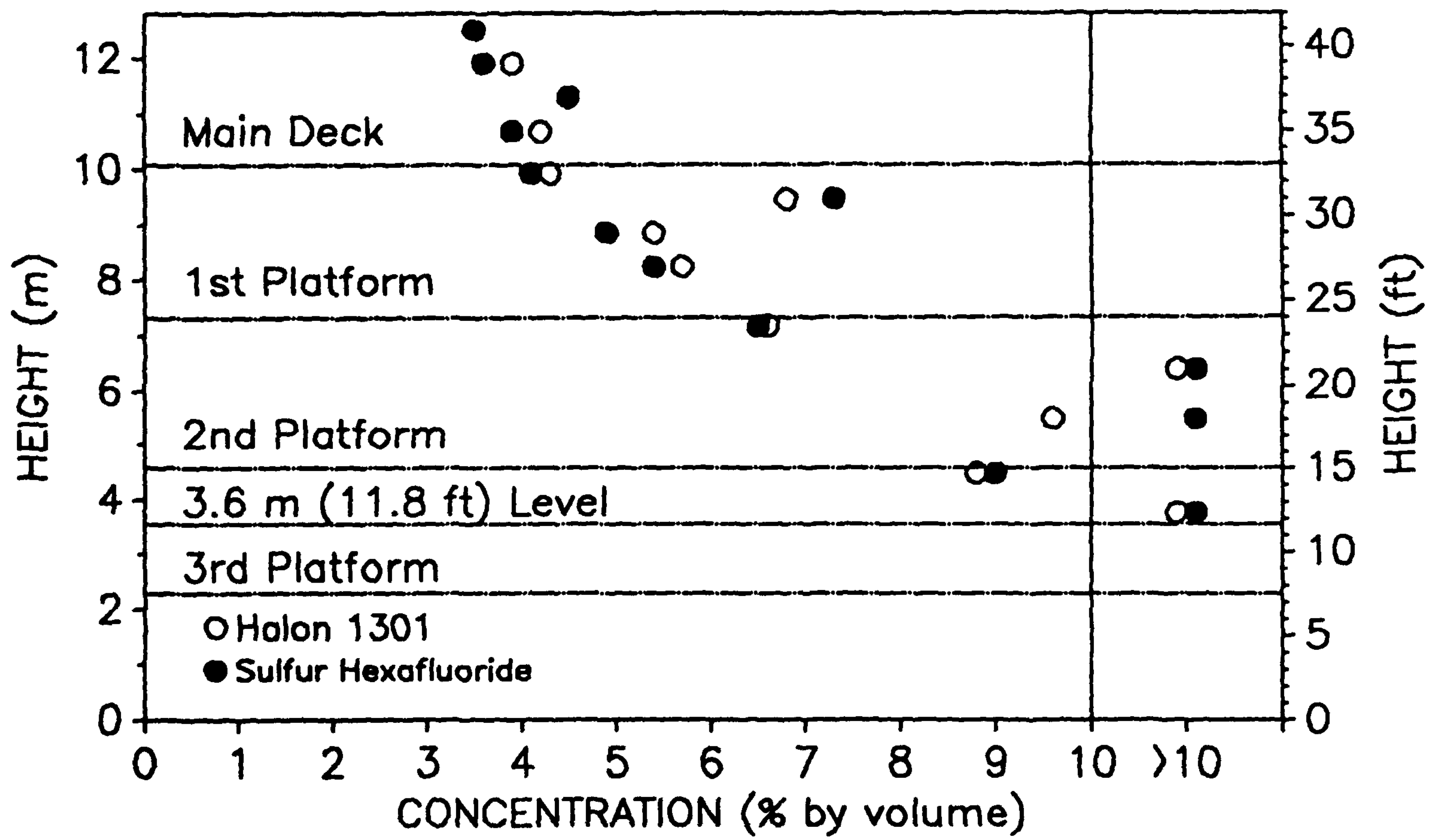

Fig. 12 — Vertical concentration profile 5 minutes after discharge

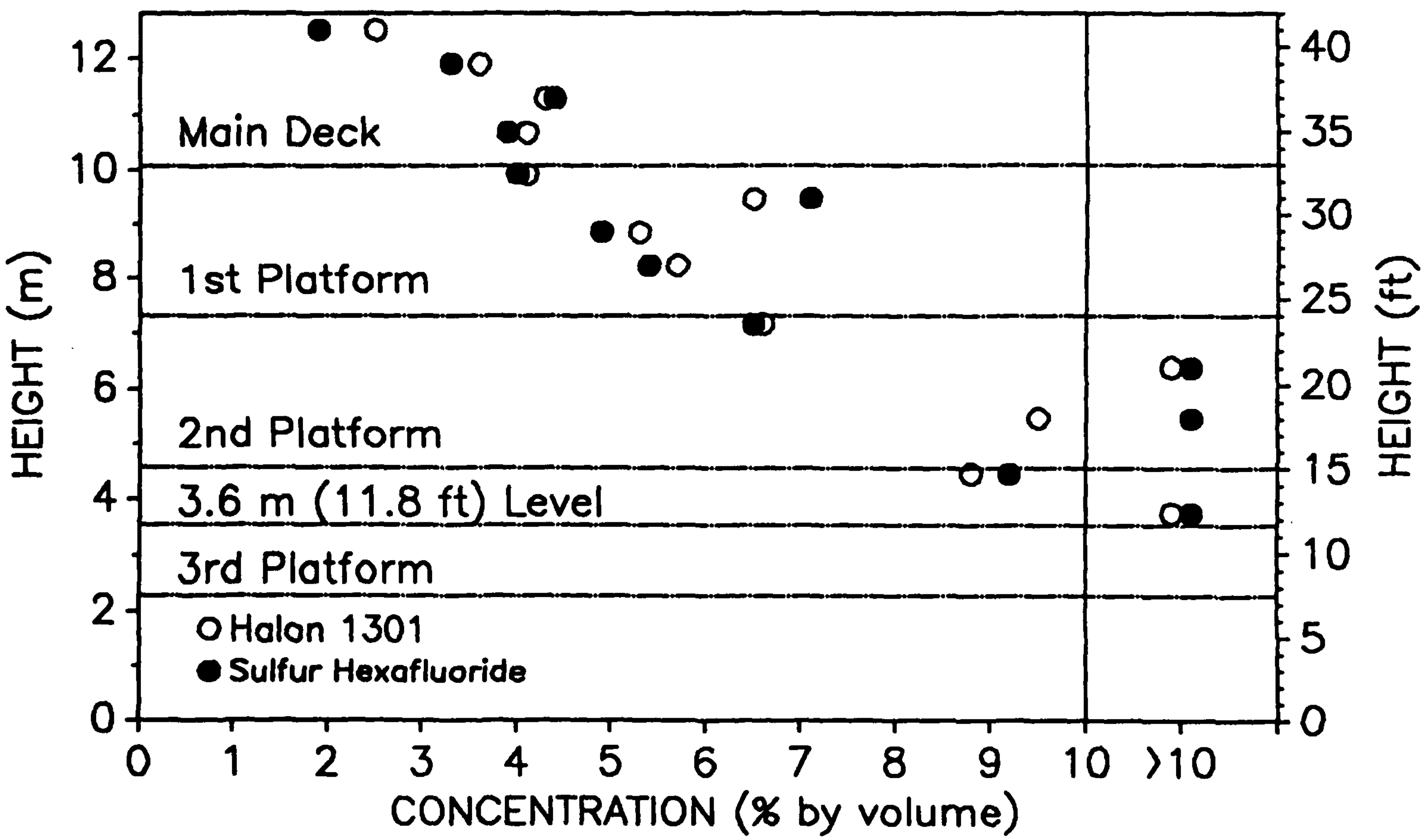

Fig. 13 — Vertical concentration profile
10 minutes after discharge

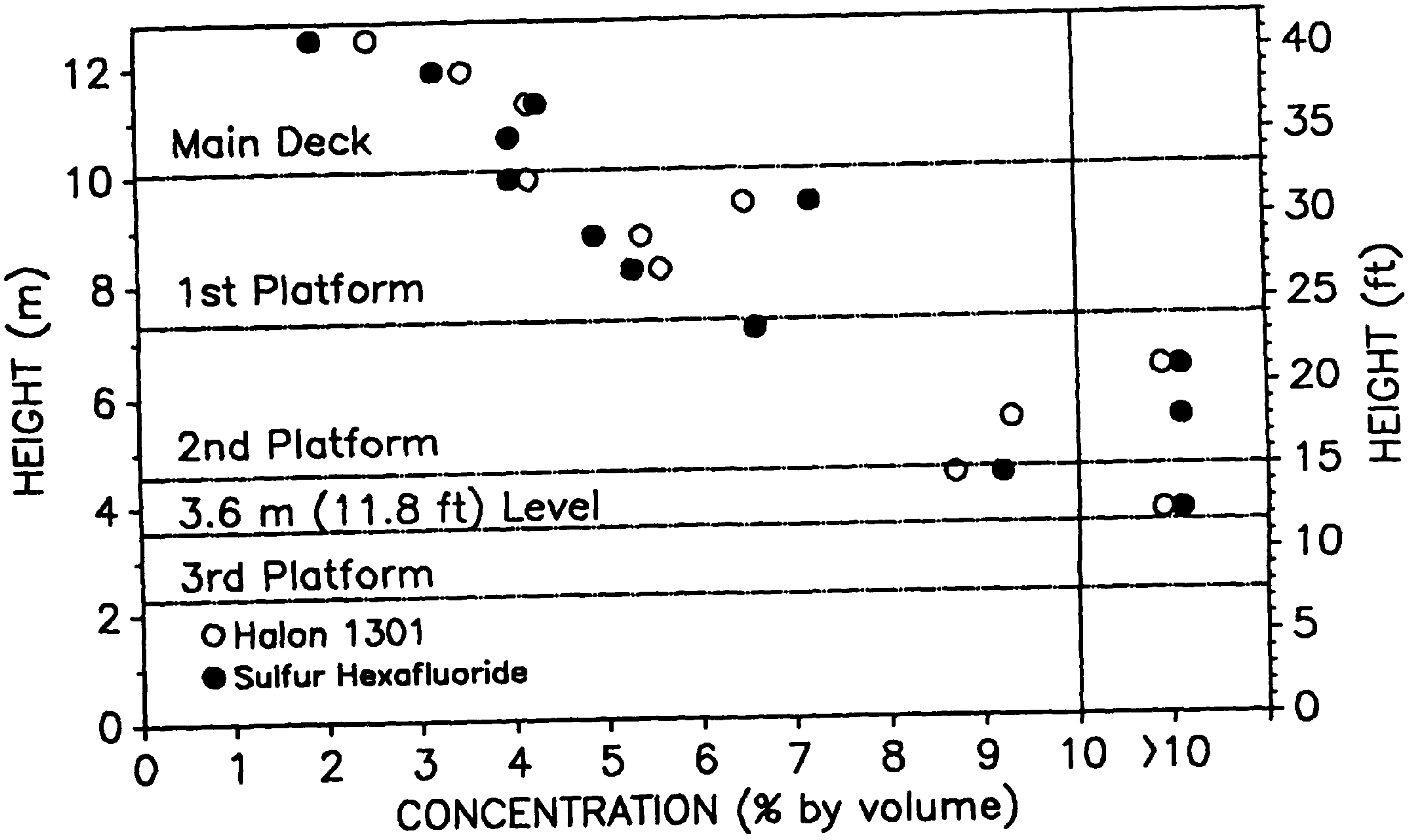

Fig. 14 – Vertical concentration profile 15 minutes after discharge

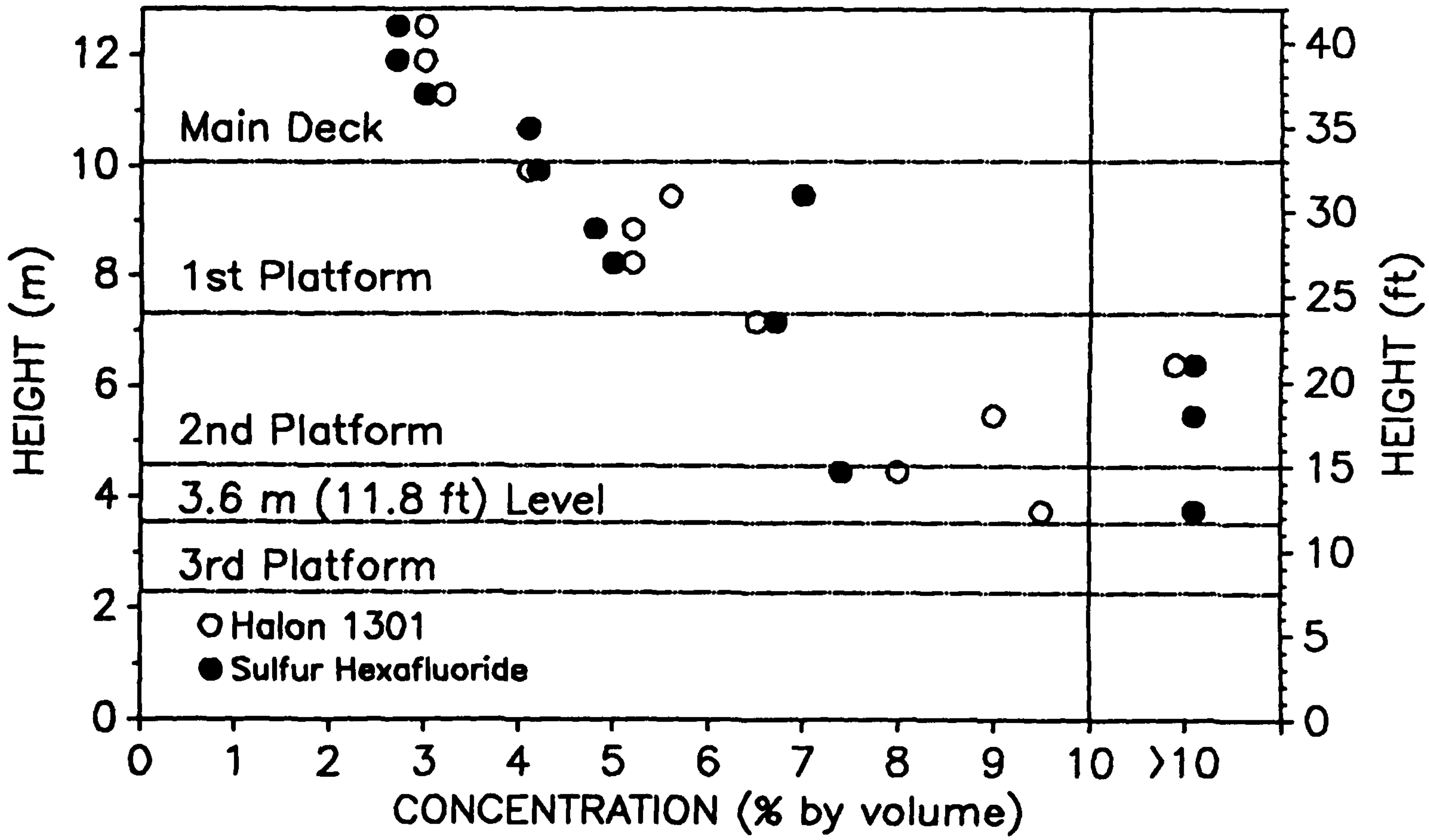

Fig. 15 — Vertical concentration profile 60 minutes after discharge

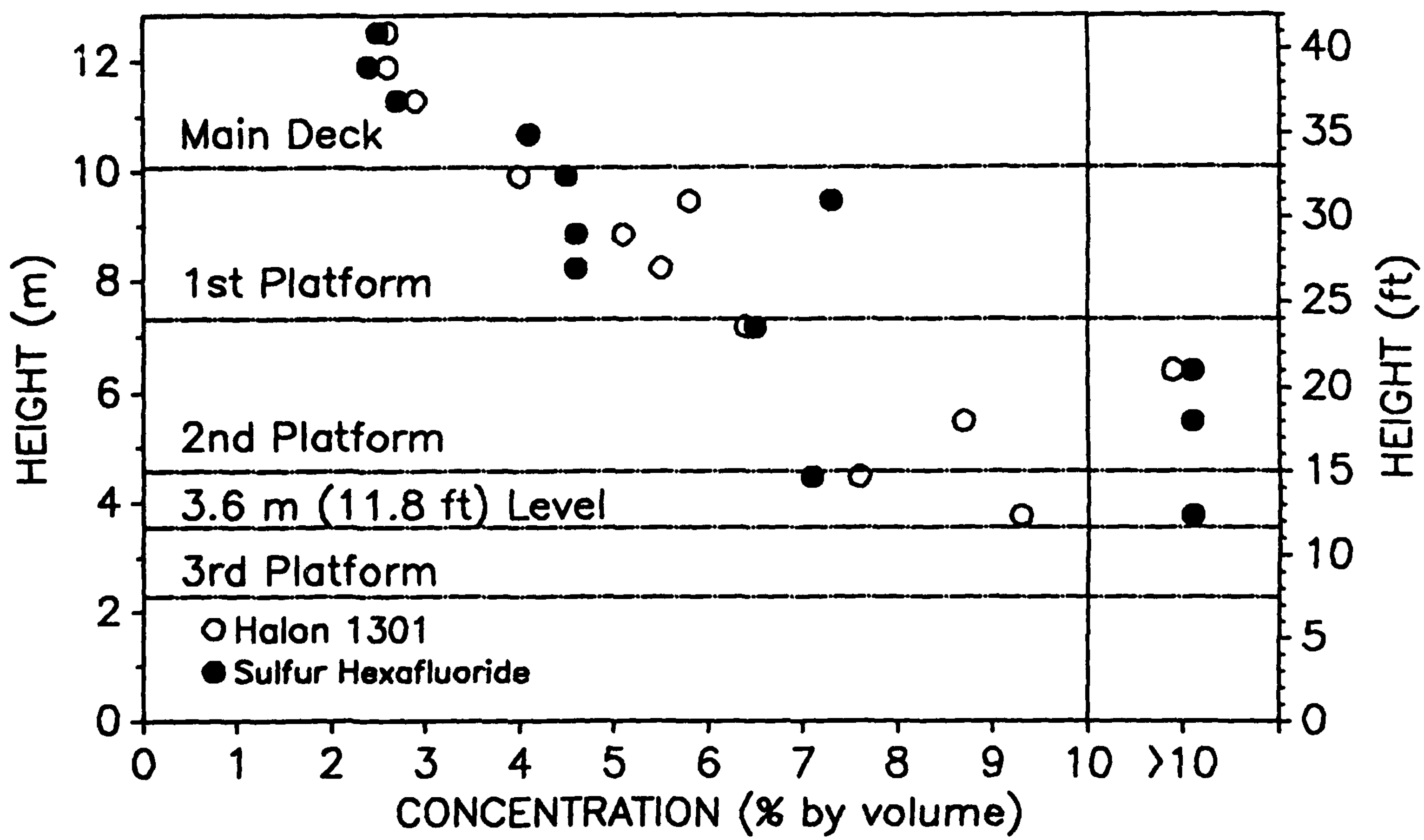

Fig. 16 – Vertical concentration profile 110 minutes after discharge

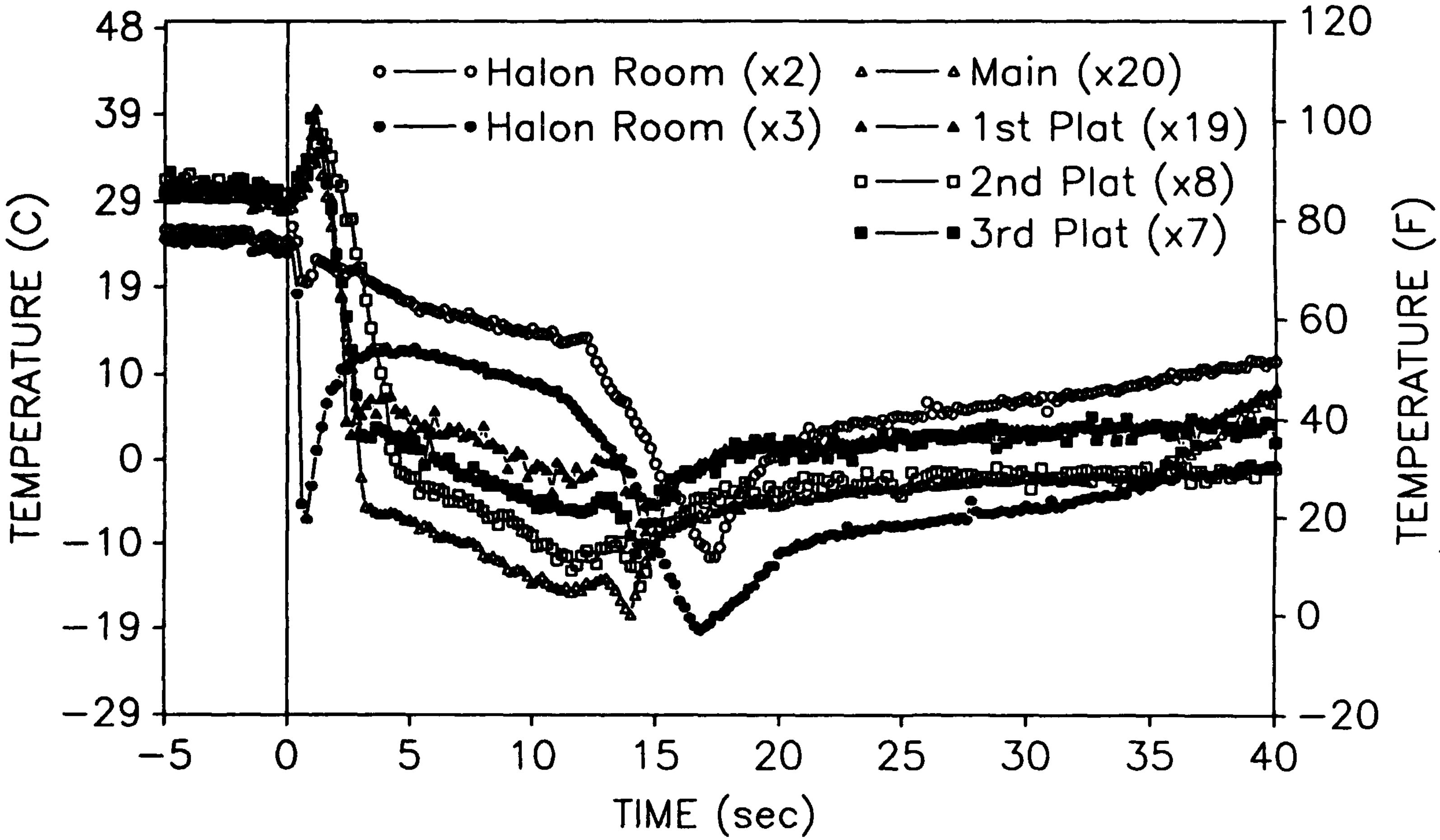

Fig. 17 – Temperature of flowing Halon 1301 at representative locations

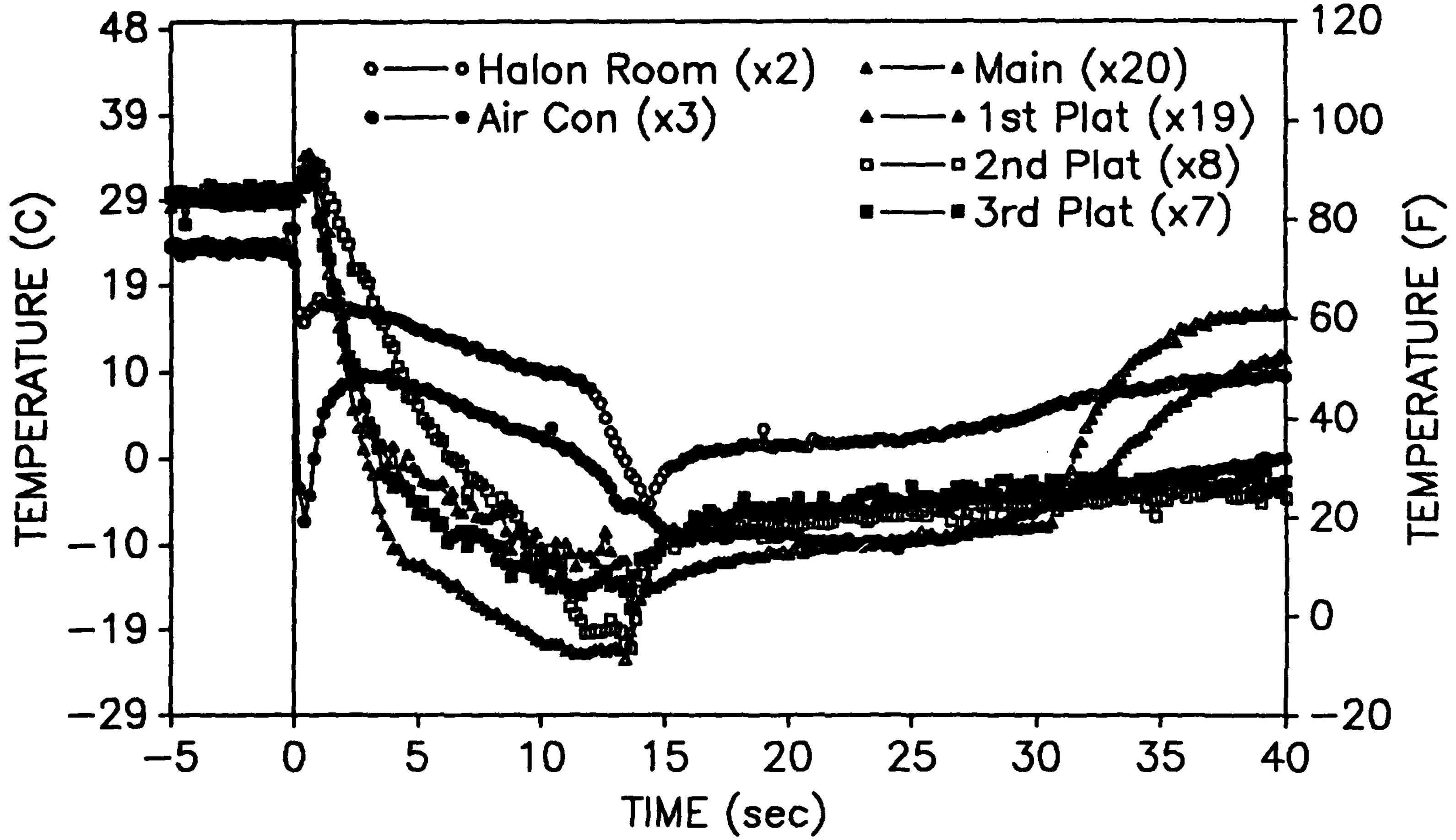

Fig. 18 — Temperature of flowing sulfur hexafluoride at representative locations

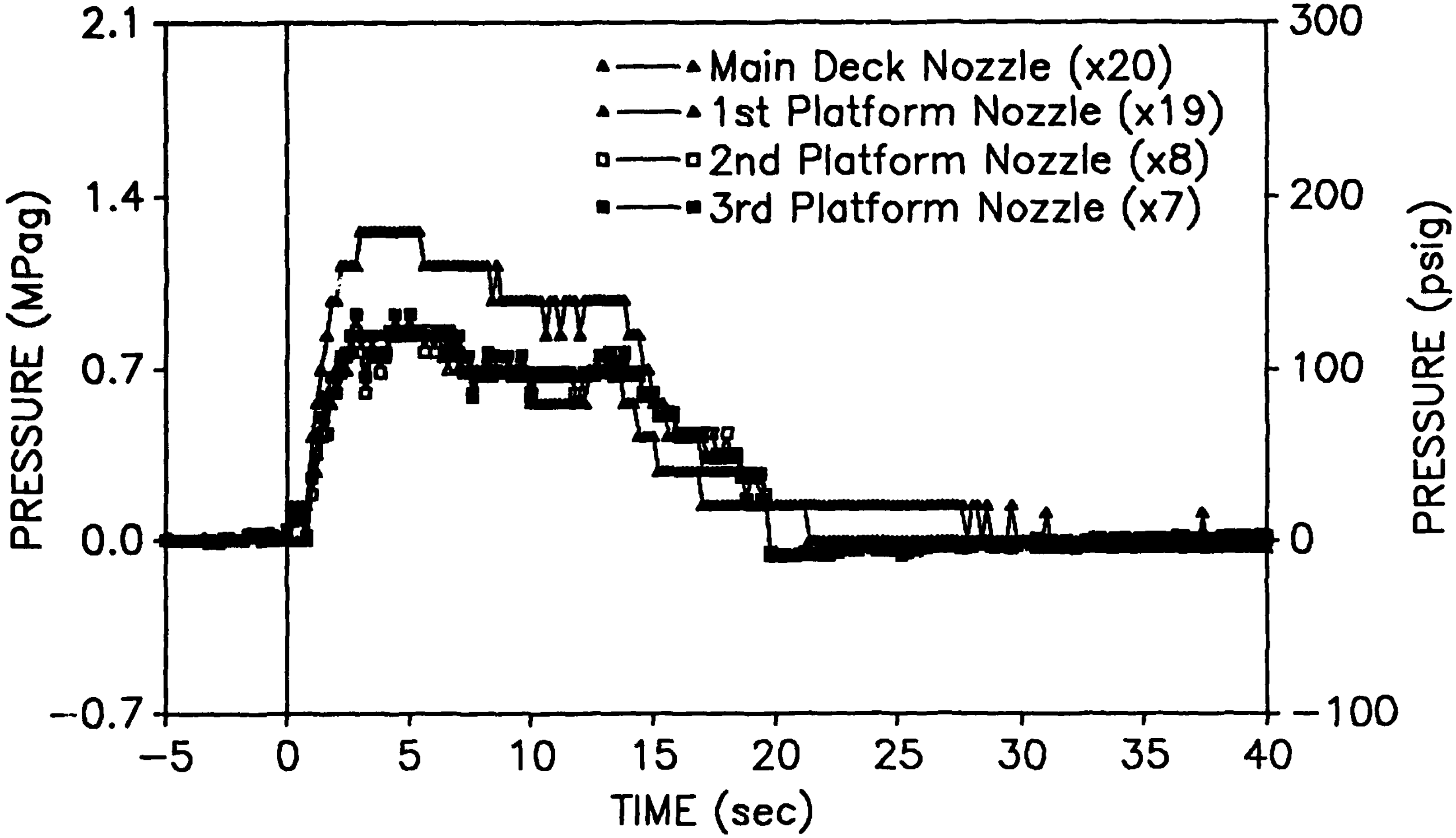

Fig. 19 — Representative nozzle pressures during Halon 1301 discharge

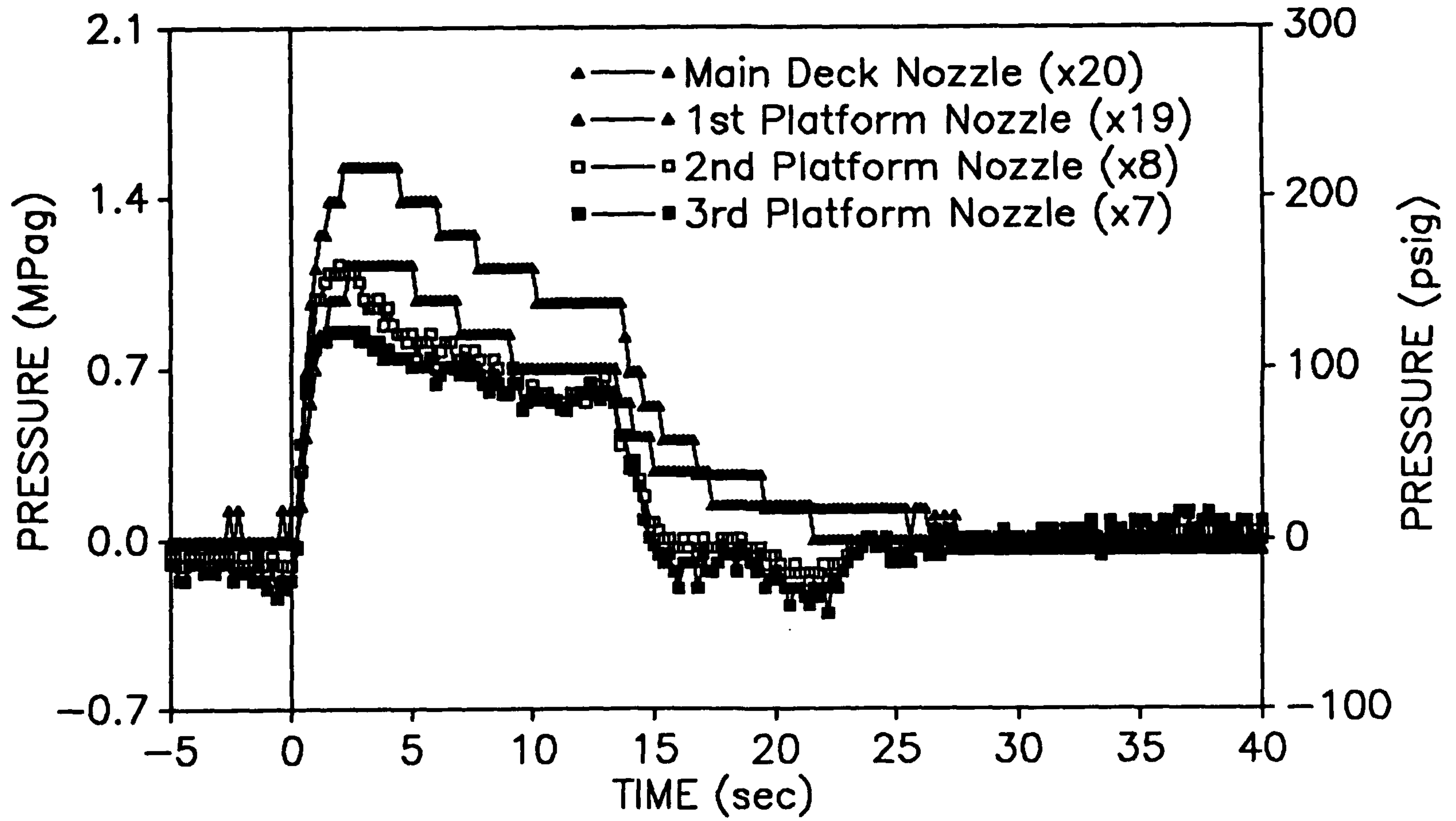

Fig. 20 — Representative nozzle pressures during sulfur hexafluoride discharge

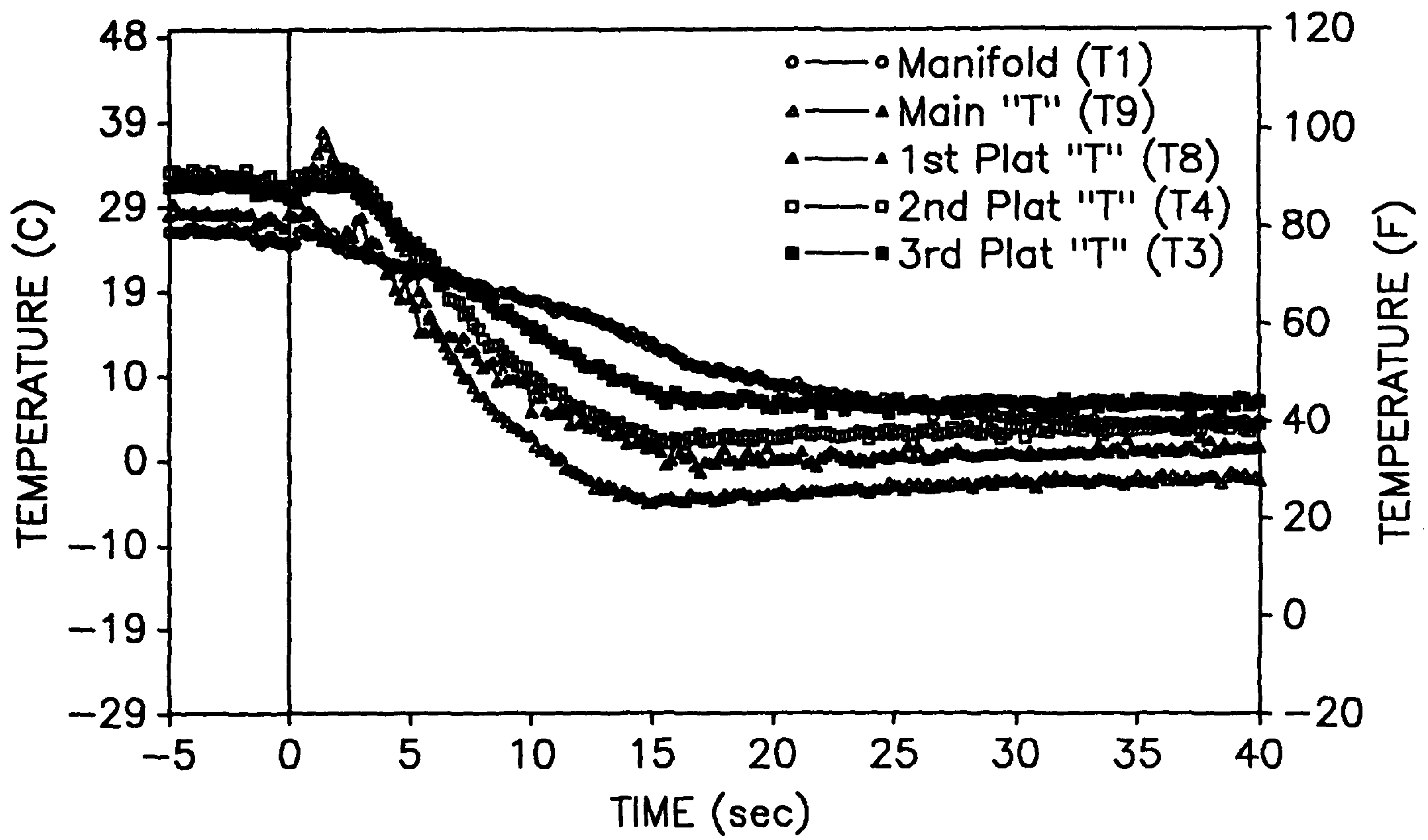

Fig. 21 — Temperature of exterior pipe walls at representative locations during Halon 1301 discharge

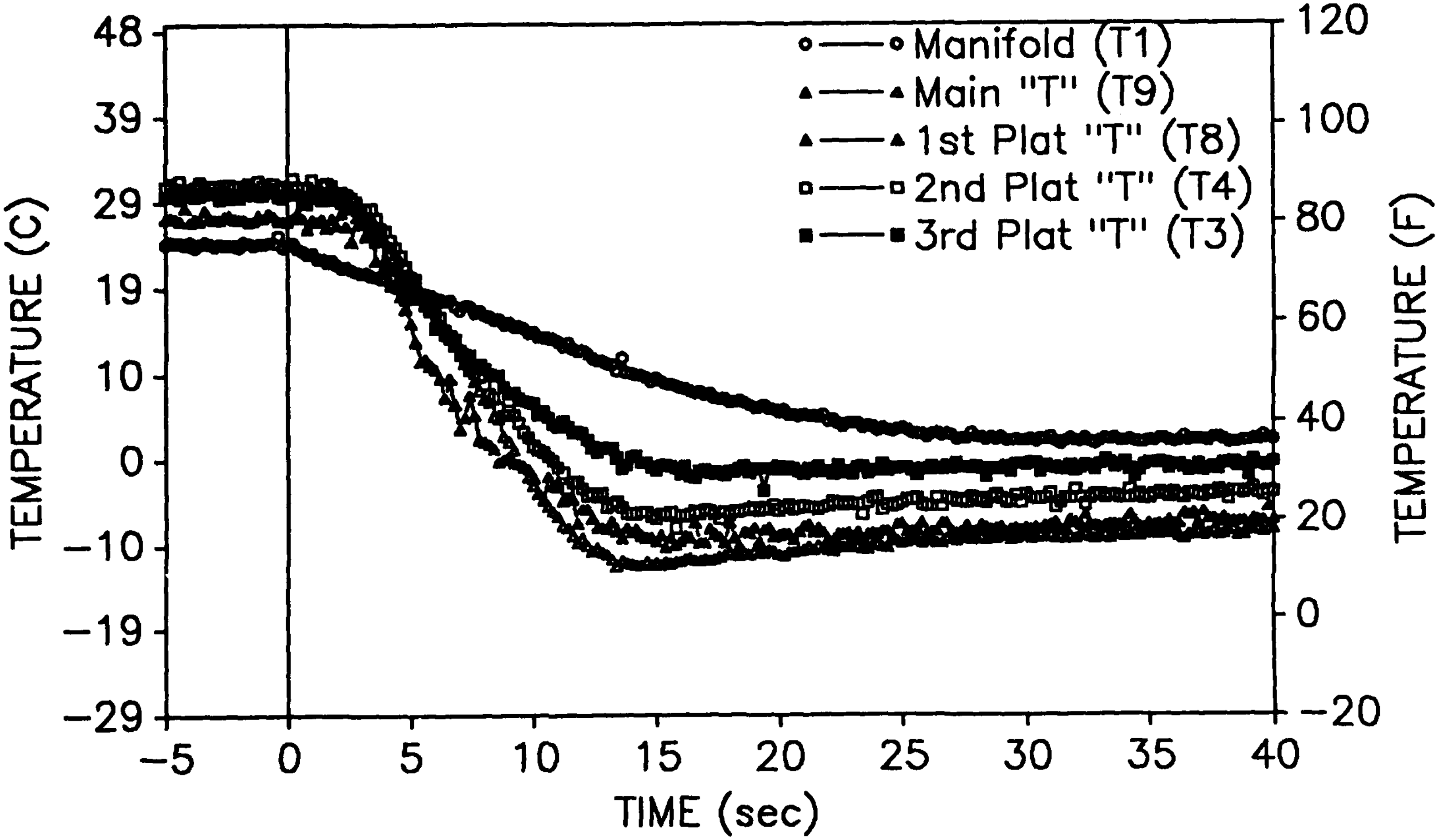

Fig. 22 — Temperature of exterior pipe walls at representative locations during sulfur hexafluoride discharge

the relationships between the specific locations are similar for both agents. The external pipe wall temperatures for other locations are given in Appendix A.

Other results obtained in these tests that do not specifically apply to the use of sulfur hexafluoride as a test agent for Halon 1301 systems are presented in Appendix B (ventilation system effects) and (an evaluation of system performance) in Appendix C.

5.0 CONCLUSIONS.

Together with the previous small scale work, these tests have shown sulfur hexafluoride to be an excellent simulant for Halon 1301 when used in discharge testing of Halon 1301 total flooding fire protection systems. Sulfur hexafluoride should be used in all discharge testing of Halon 1301 total flooding fire protection systems that employ hardware and system parameters (fill density, percent agent in pipe, etc.) that are similar to those employed by the U.S. Navy.

6.0 RECOMMENDATIONS.

Recommended areas for further study include the effects of system parameters and hardware that are not considered to be representative of systems presently used by the U.S. Navy. Most systems employed by private industry have significant differences in both system parameters and hardware that might effect the degree to which sulfur hexafluoride simulates Halon 1301.

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APPENDIX A

APPENDIX A

Concentration, Temperature, and Pressure Traces

The concentration traces obtained for both Halon 1301 and sulfur hexafluoride are shown in Figures 23 through 55. Sampling points 18, 23, and 27 ran off scale for Halon 1301 and are not shown. Sampling point 30 was moved in between the Halon 1301 test and the SF_6 test. Sampling point exhaust 1 quit reading approximately 90 minutes into the SF_6 test (the sampling tube probably developed a clog). One halon analyzer with sampling points 1, 2, and 3 had a delayed start but responded at the same time as the other analyzers when the ventilation system was restarted (a broken or loose connection inside the analyzer probably caused this). Sampling point 9 was exchanged with sampling point 2 in between tests to make sure the problem was not in the tubes.

The temperatures of the flowing Halon 1301 and sulfur hexafluoride are shown in Figures 56 through 67. The thermocouple at point x1 was blown out of its compression fitting during the Halon 1301 test and is not shown. The thermocouple at point x9 was also blown out of its compression fitting but was replaced inbetween tests and is shown.

The pressure of the flowing Halon 1301 and sulfur hexafluoride are shown in Figures 68 through 77. Several of the pressure traces were scrambled due to damage that occurred in transport and are not shown.

The exterior pipe wall temperatures during the Halon 1301 and sulfur hexafluoride discharges are given in Figures 78 through 85.

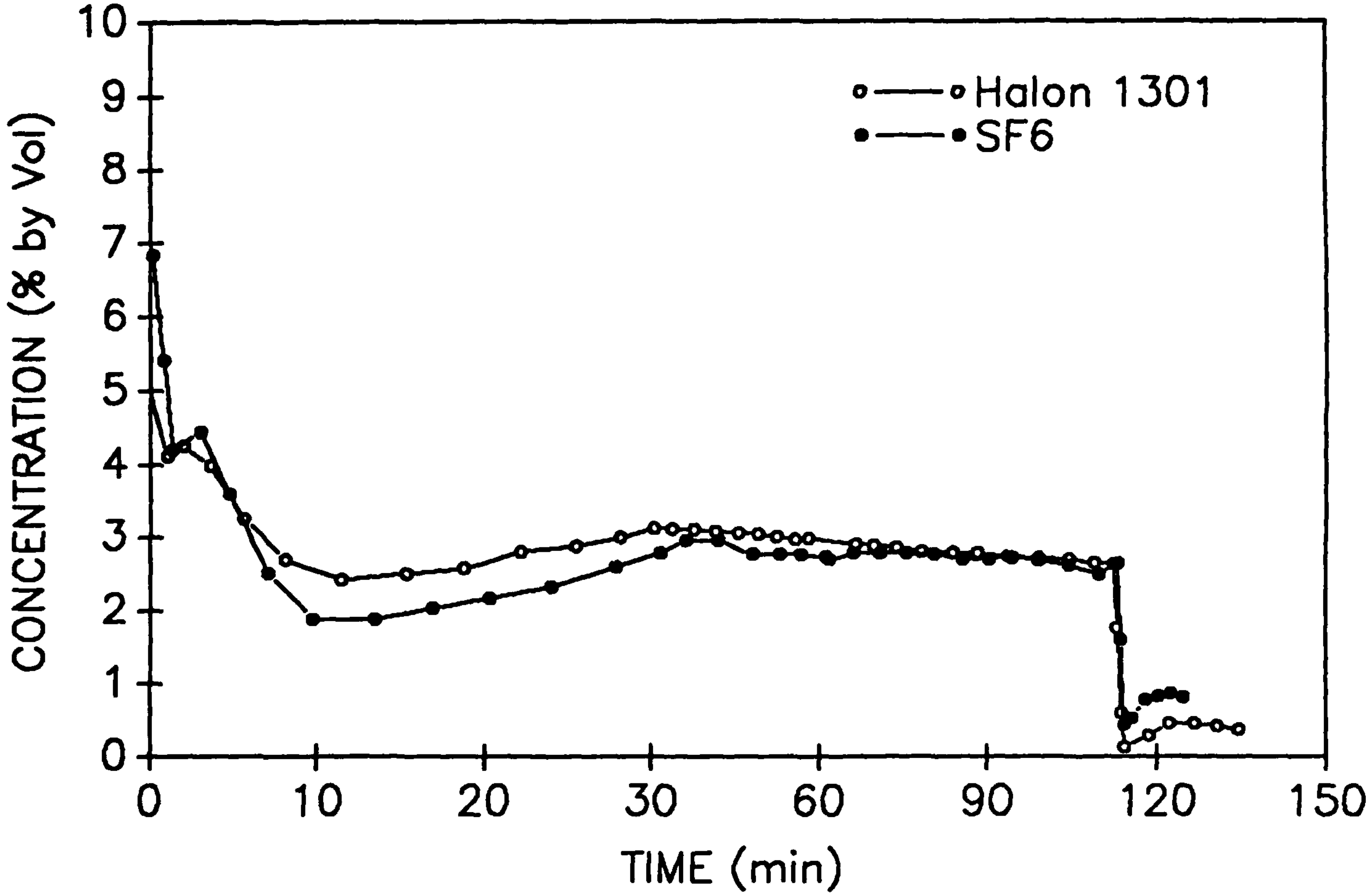

Fig. 23 — Concentration at analyzer point 1

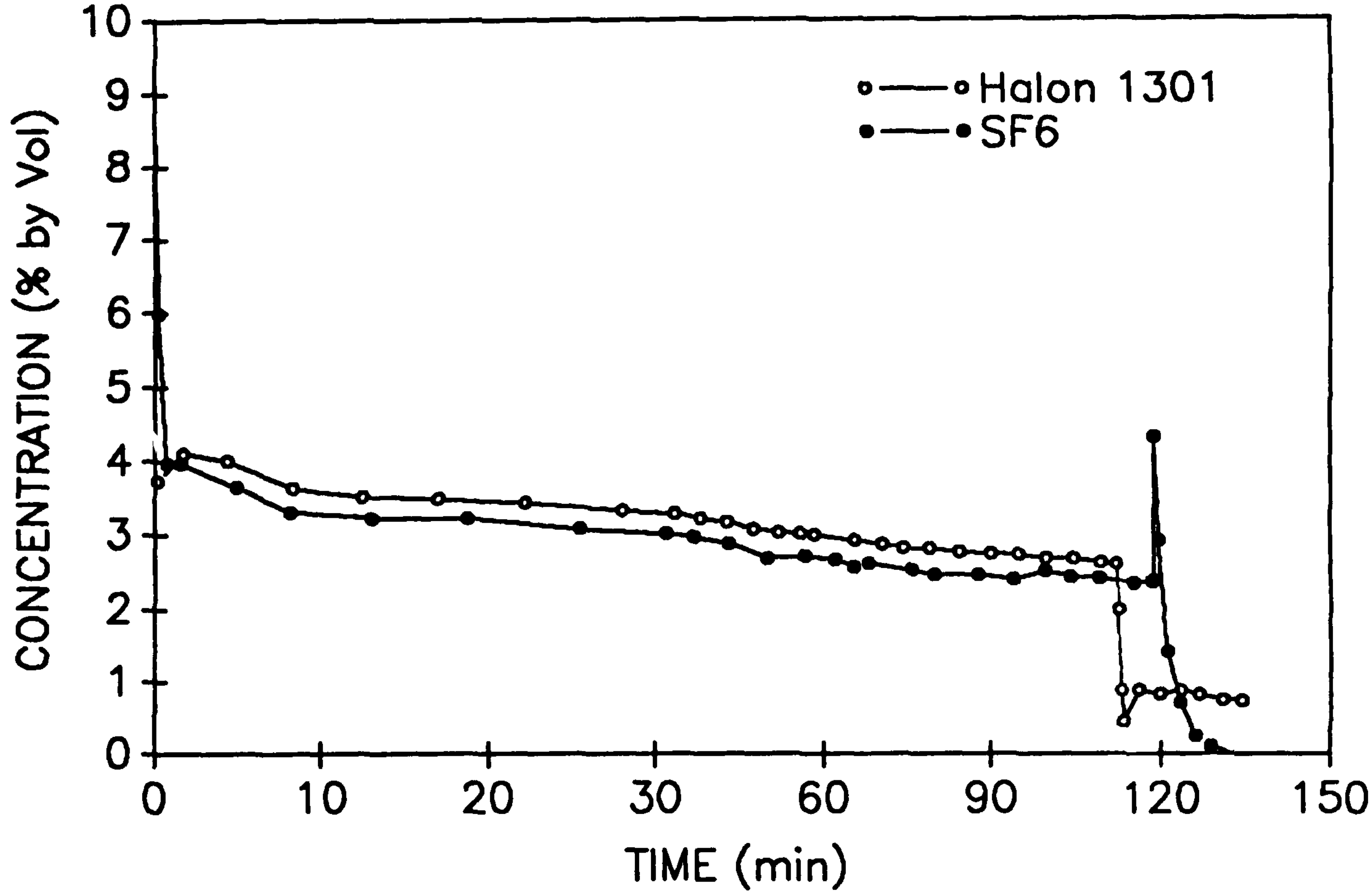

Fig. 24 — Concentration at analyzer point 2

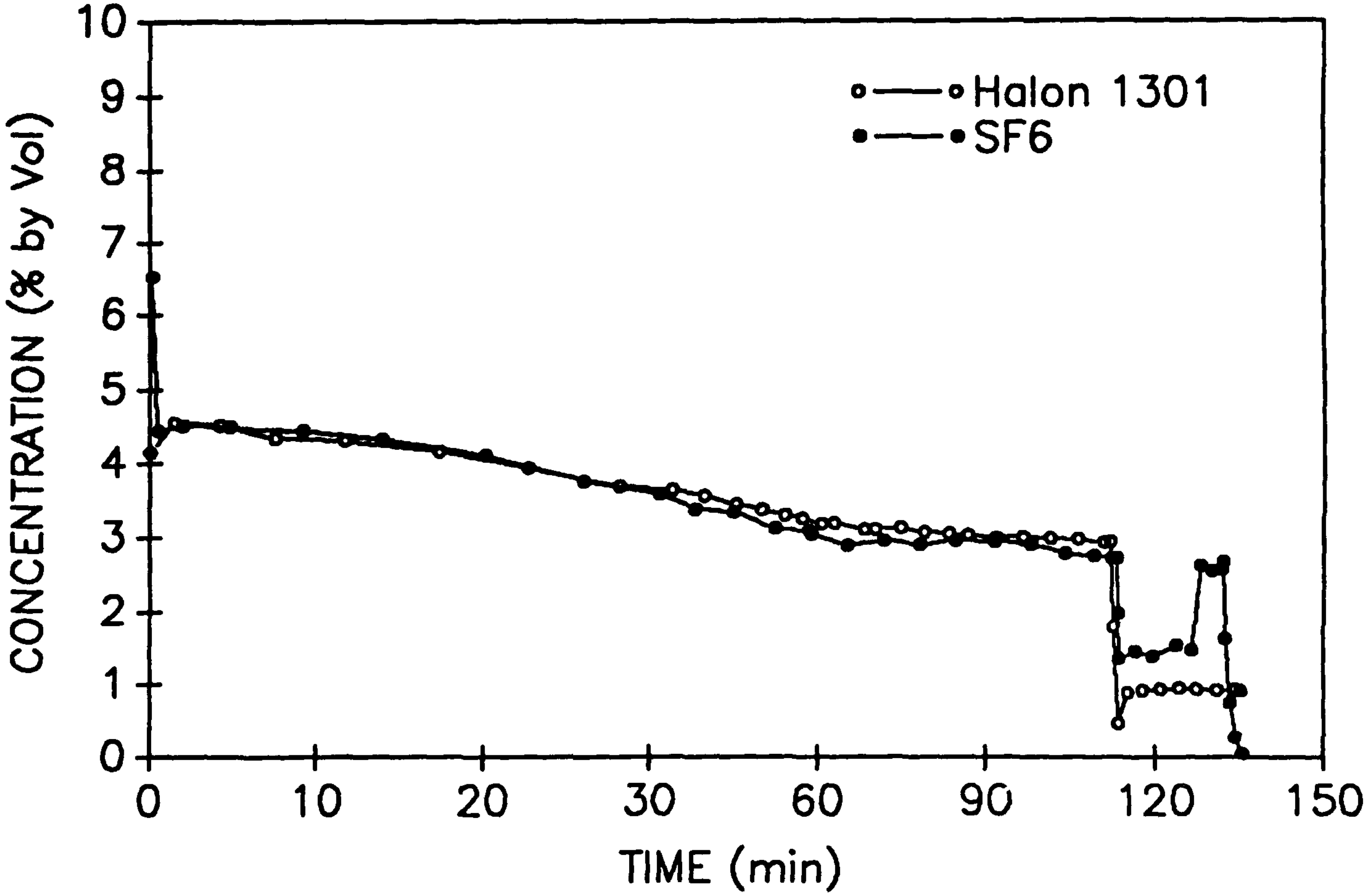

Fig. 25 — Concentration at analyzer point 3

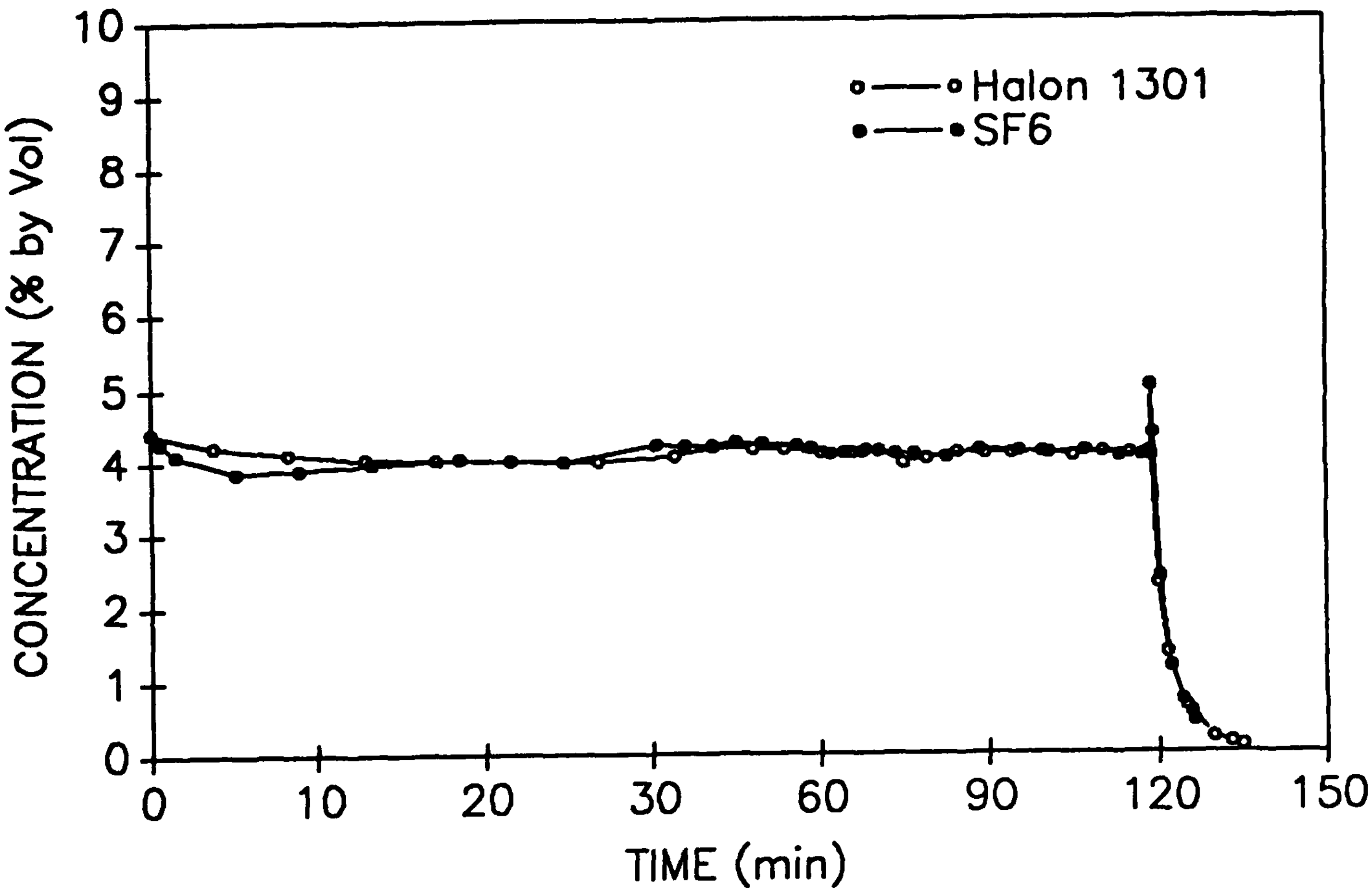

Fig. 26 — Concentration at analyzer point 4

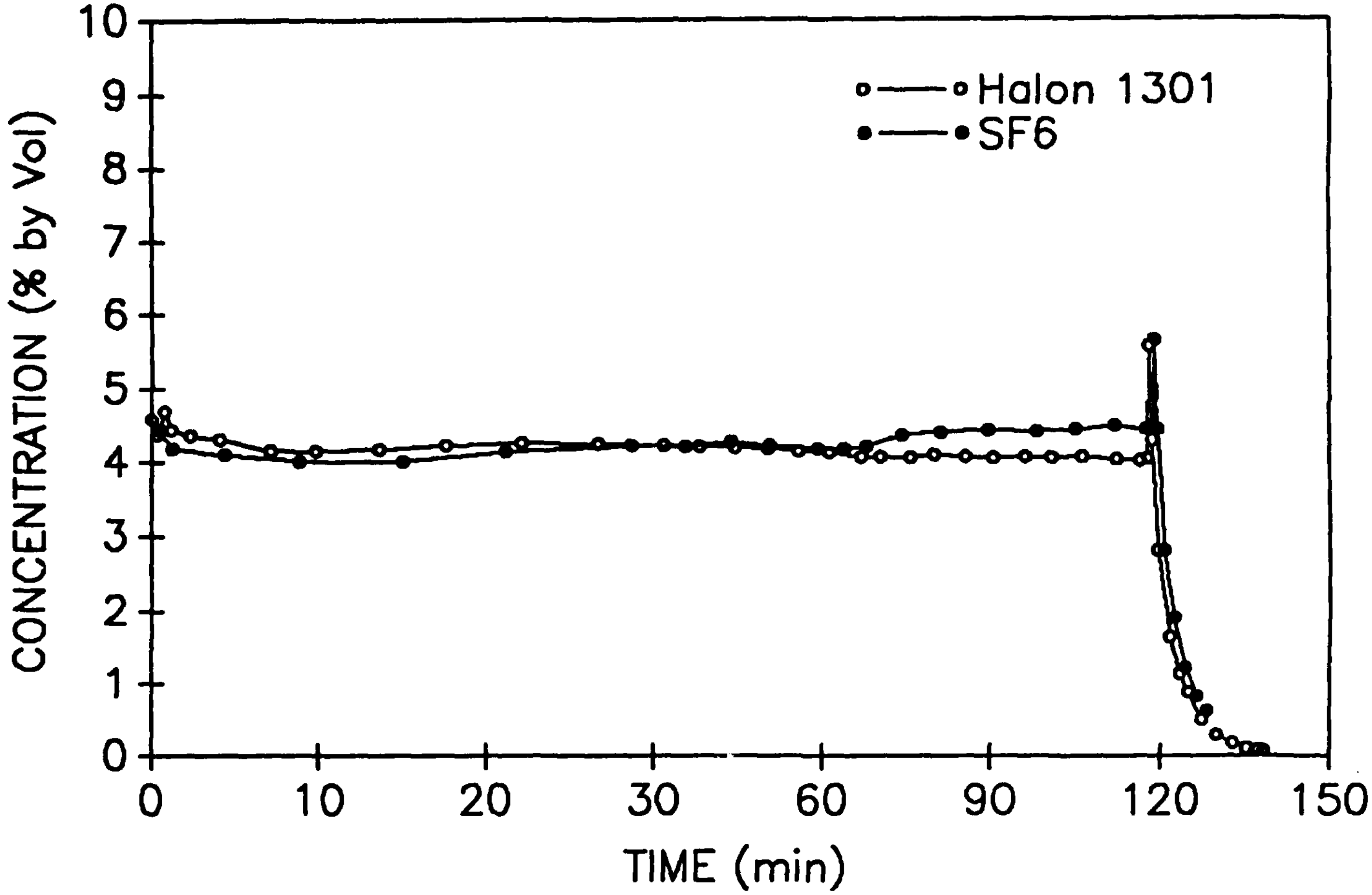

Fig. 27 — Concentration at analyzer point 5

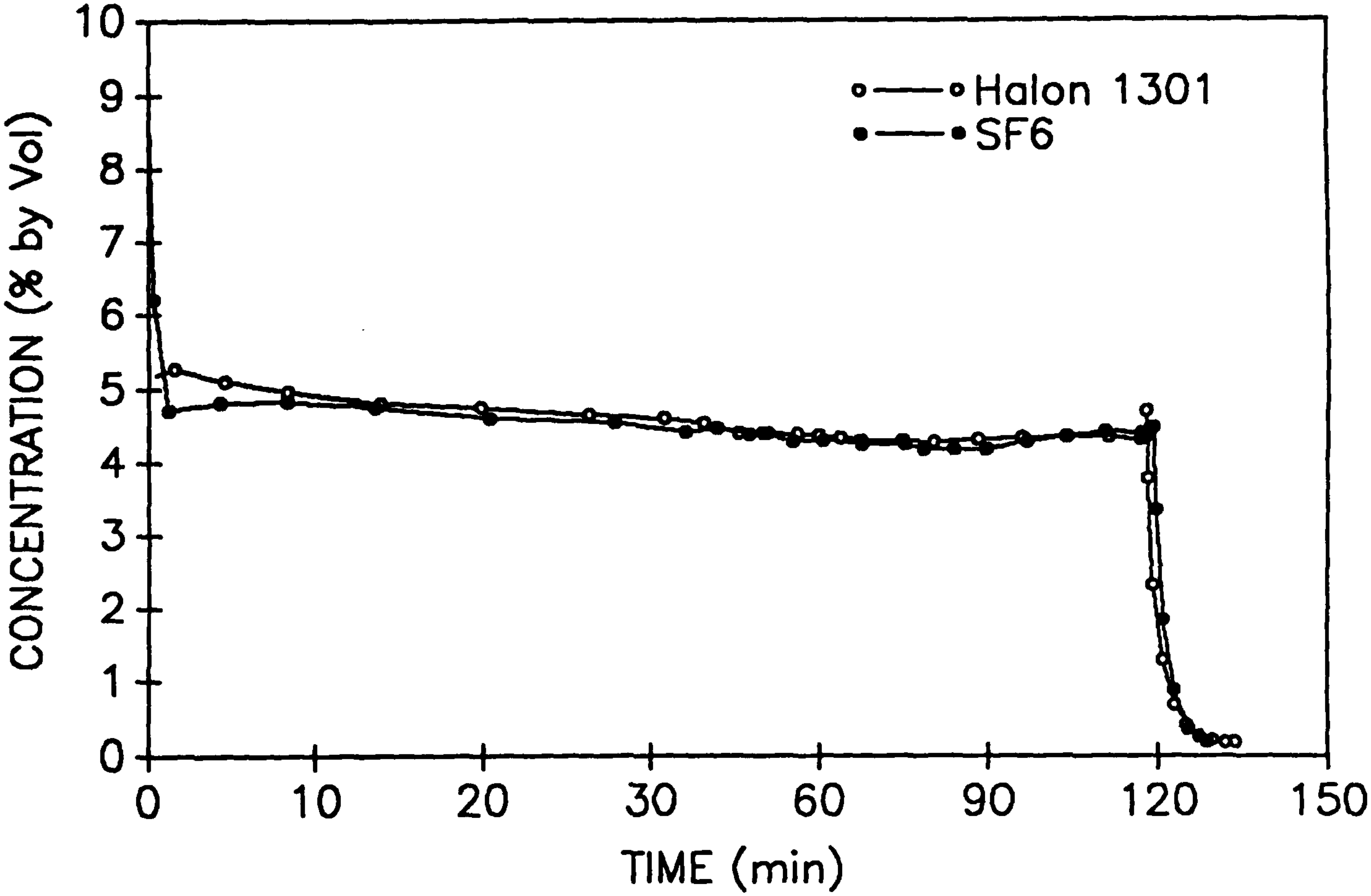

Fig. 28 — Concentration at analyzer point 6

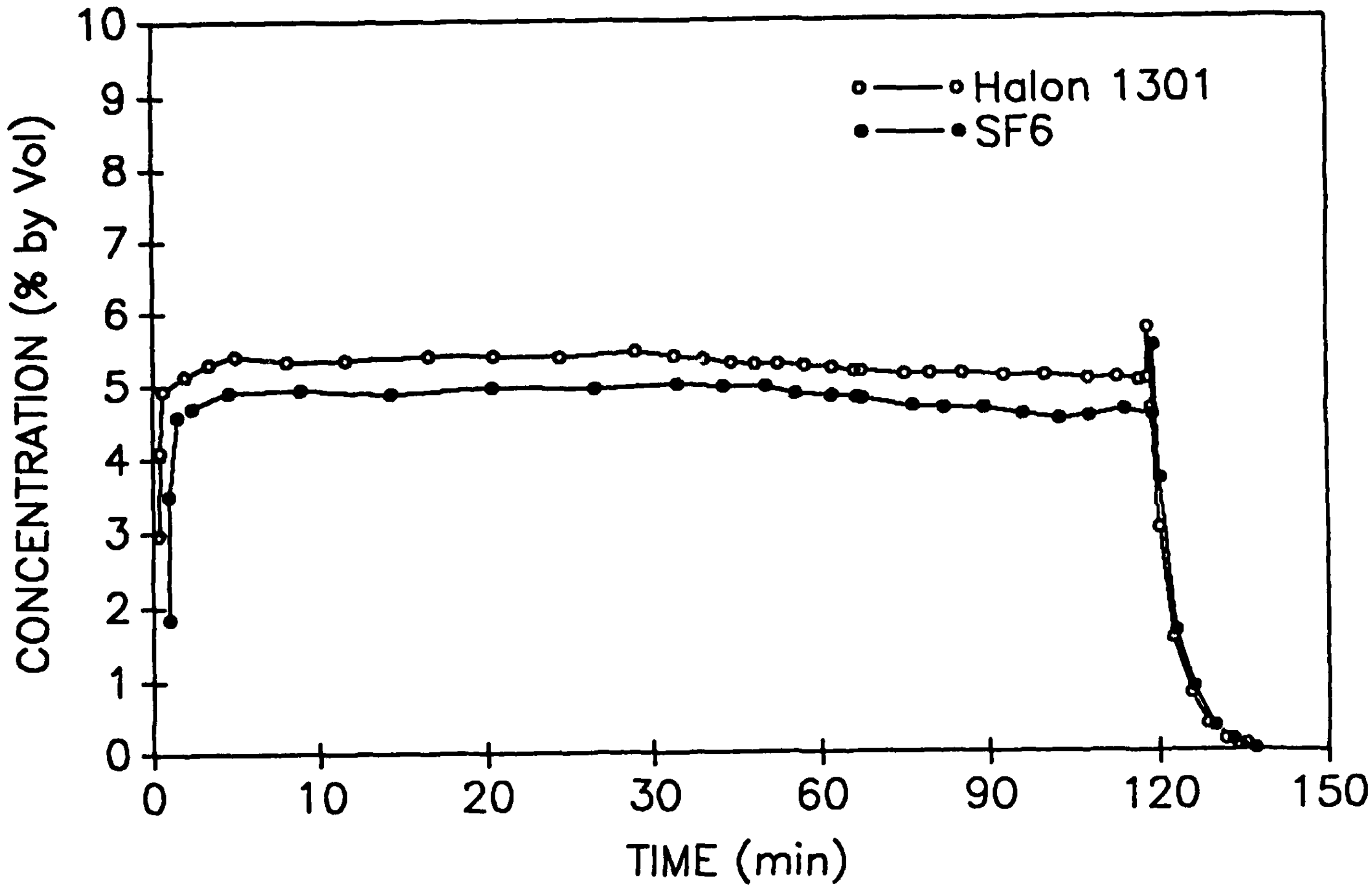

Fig. 29 – Concentration at analyzer point 7

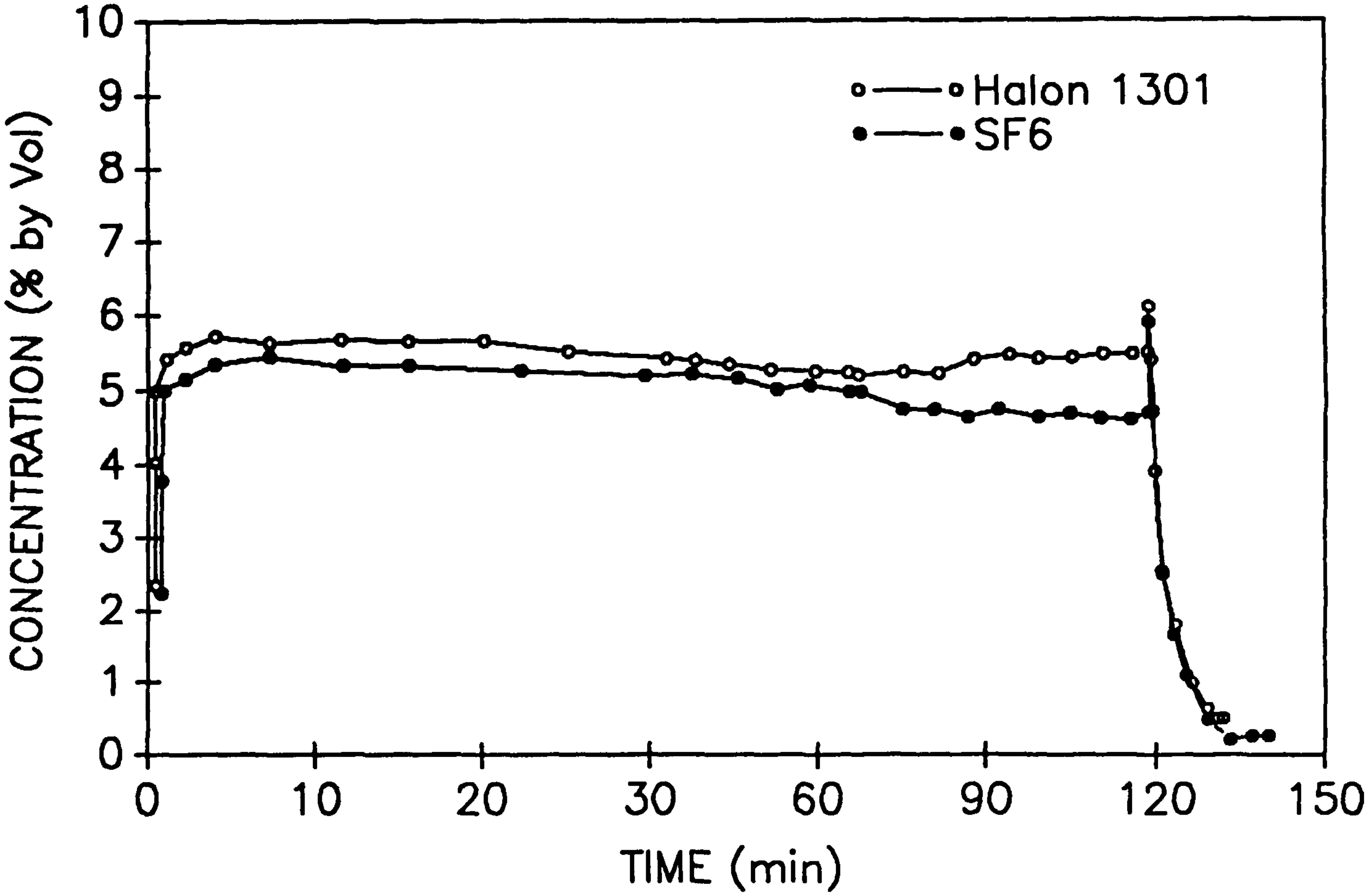

Fig. 30 — Concentration at analyzer point 8

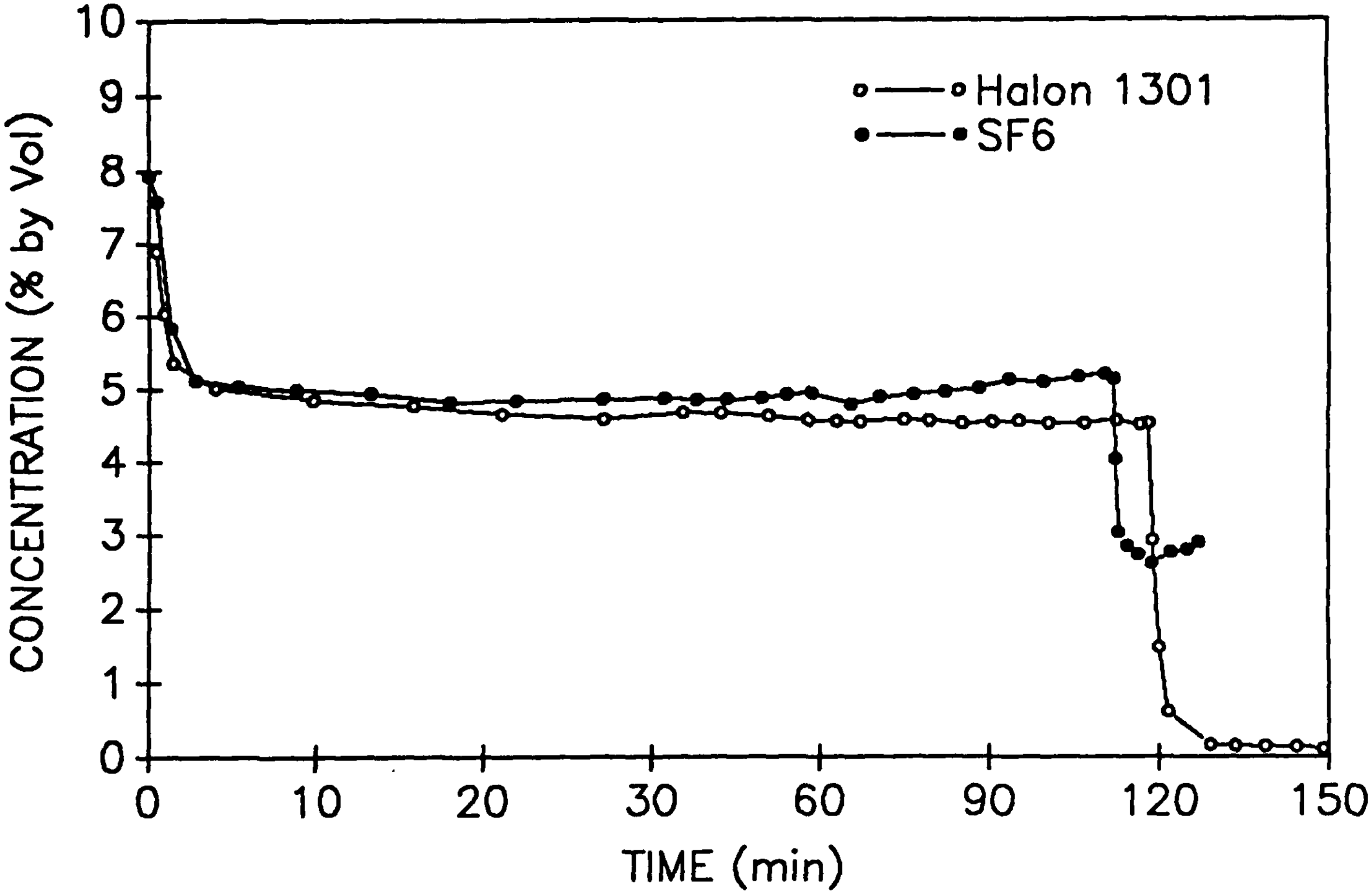

Fig. 31 — Concentration at analyzer point 9

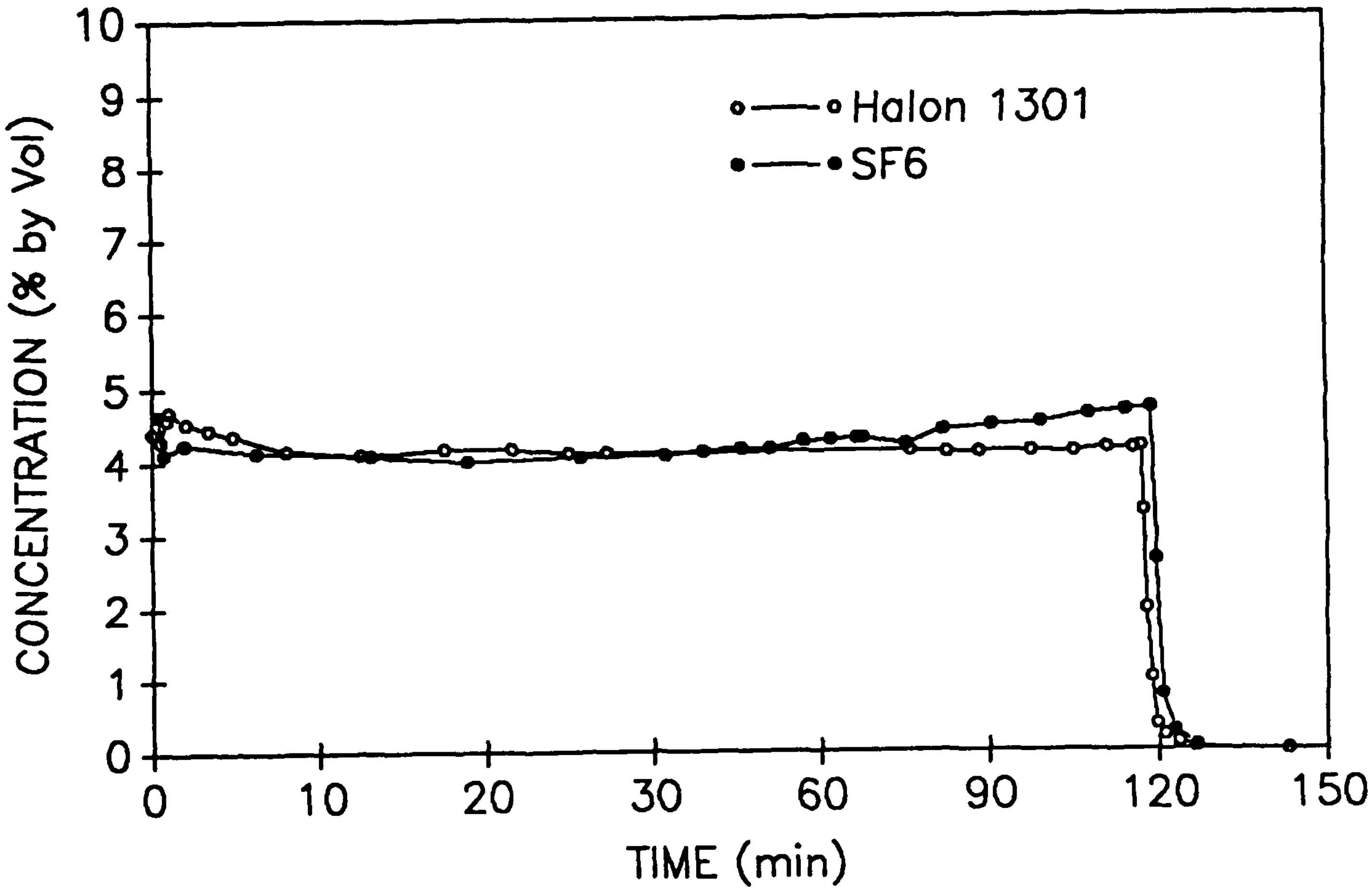

Fig. 32 — Concentration at analyzer point 10

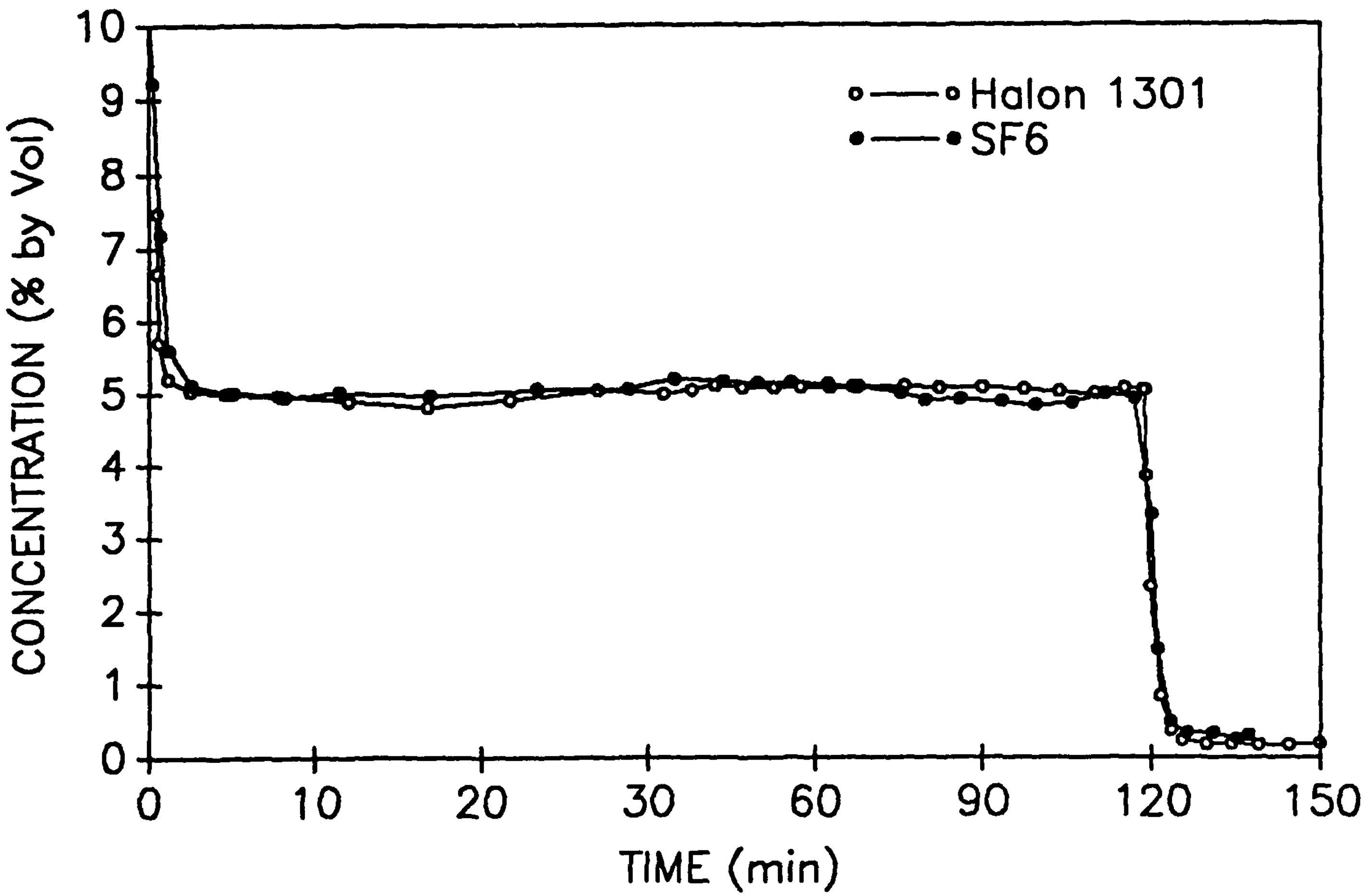

Fig. 33 — Concentration at analyzer point 11

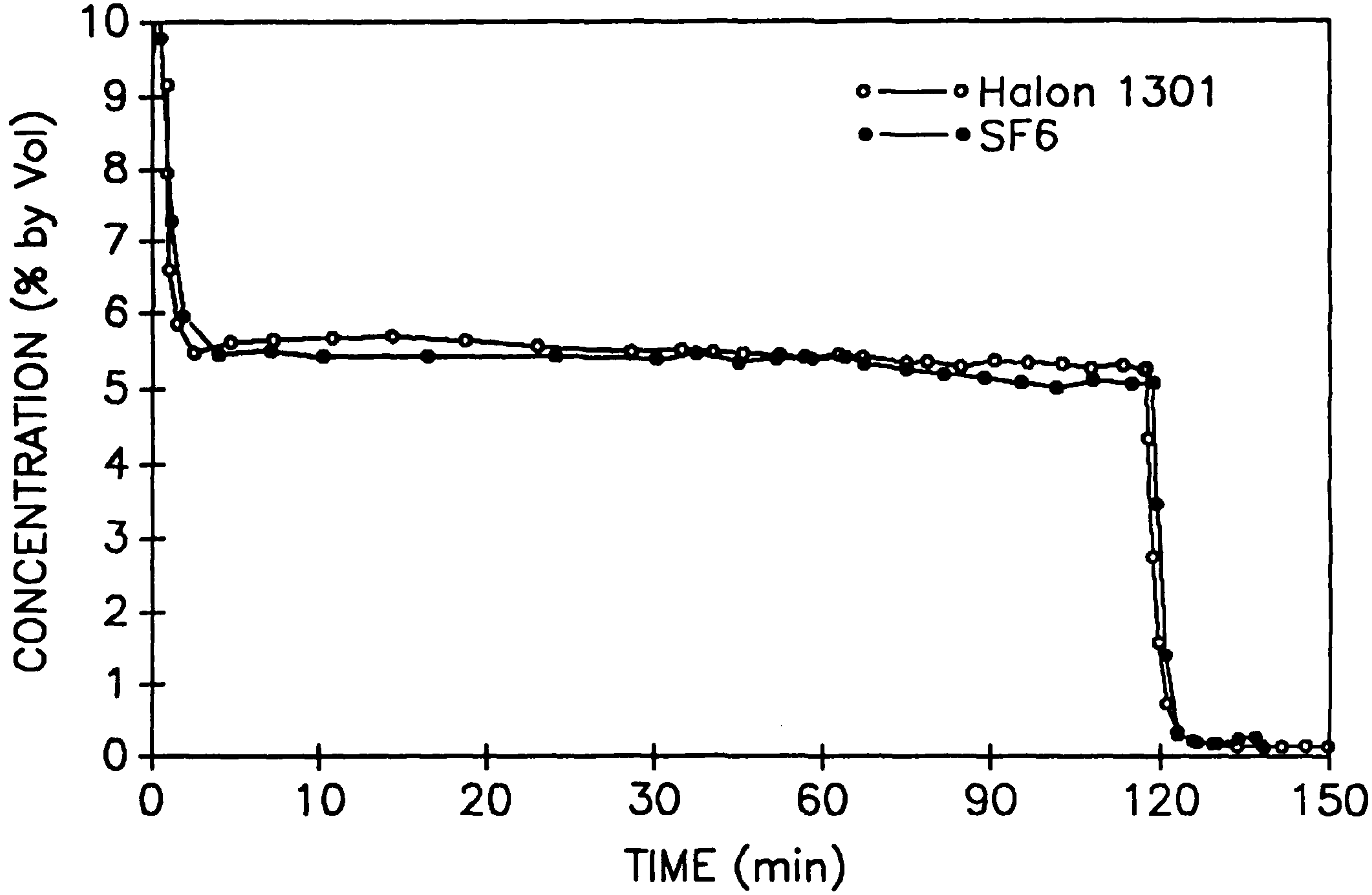

Fig. 34 – Concentration at analyzer point 12

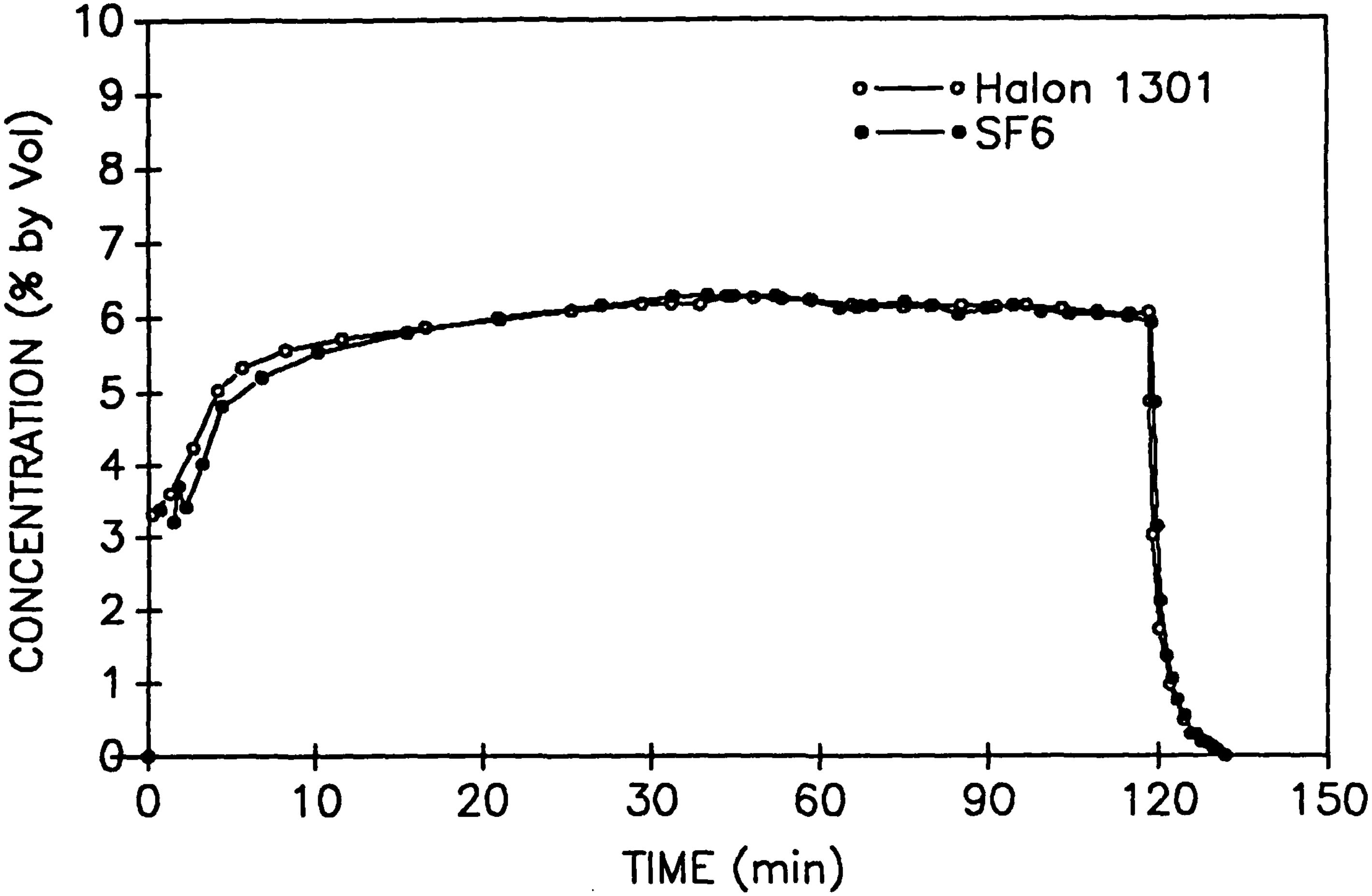

Fig. 35 – Concentration at analyzer point 13

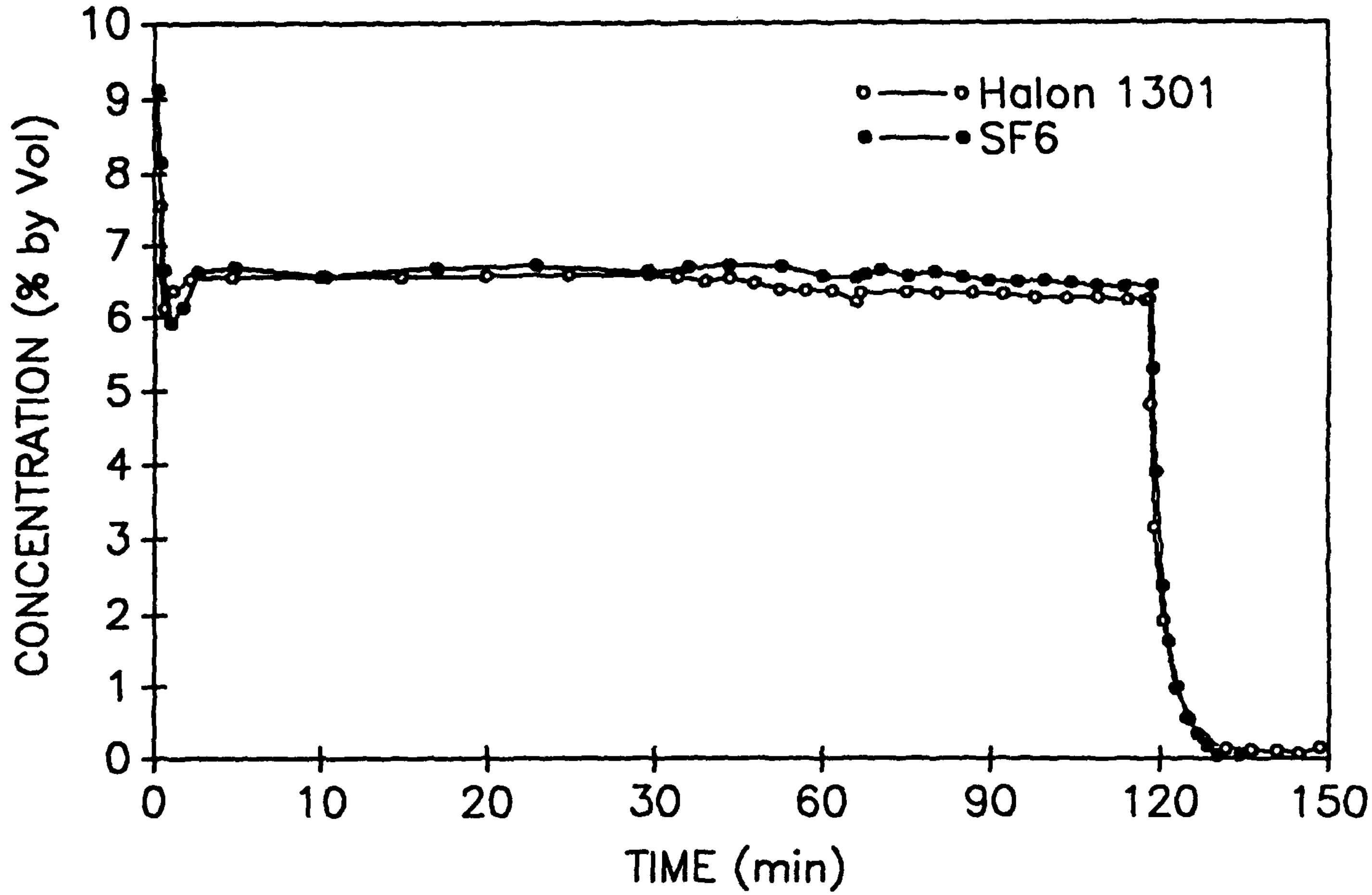

Fig. 36 — Concentration at analyzer point 14

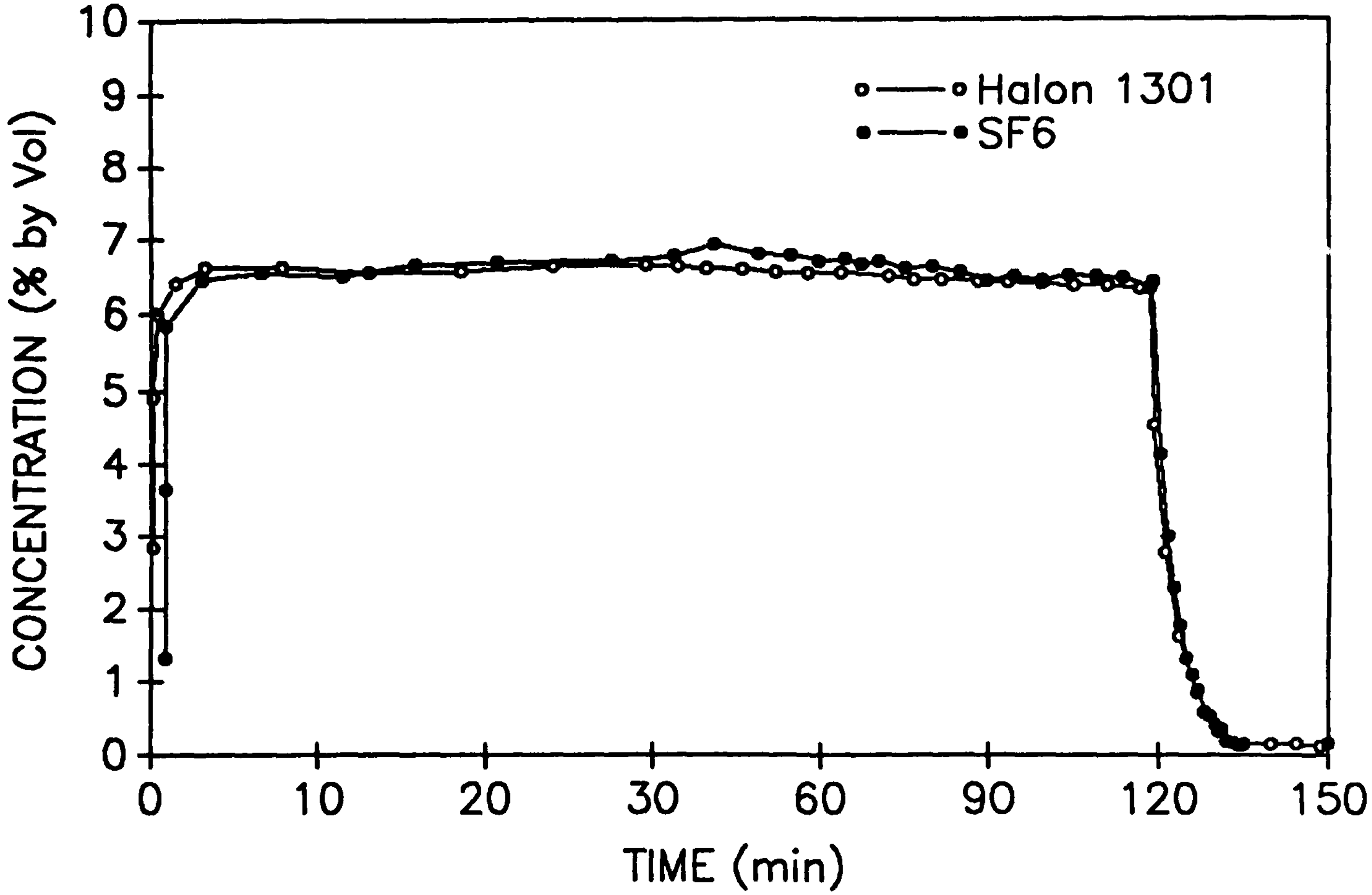

Fig. 37 — Concentration at analyzer point 15

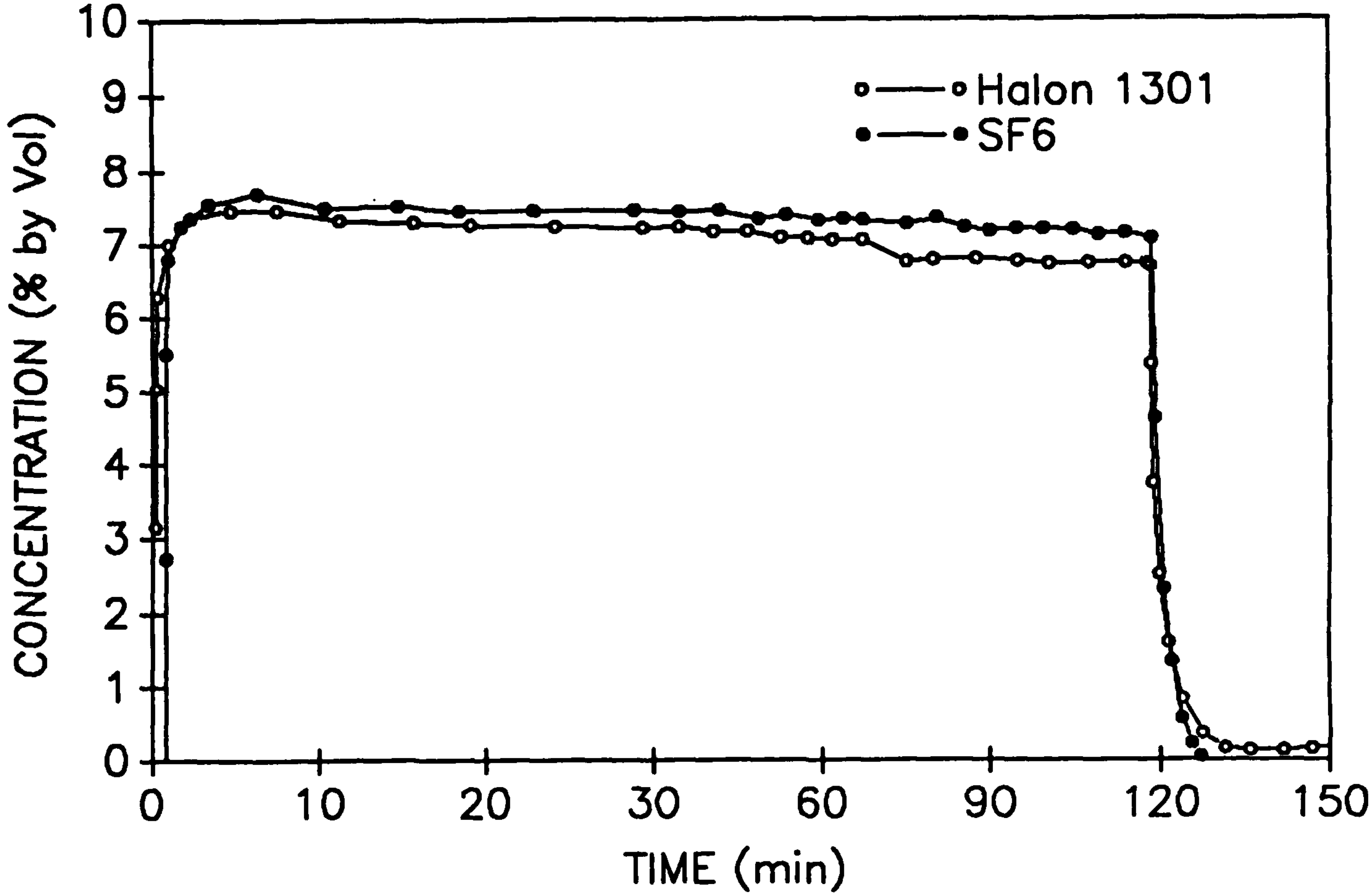

Fig. 38 – Concentration at analyzer point 16

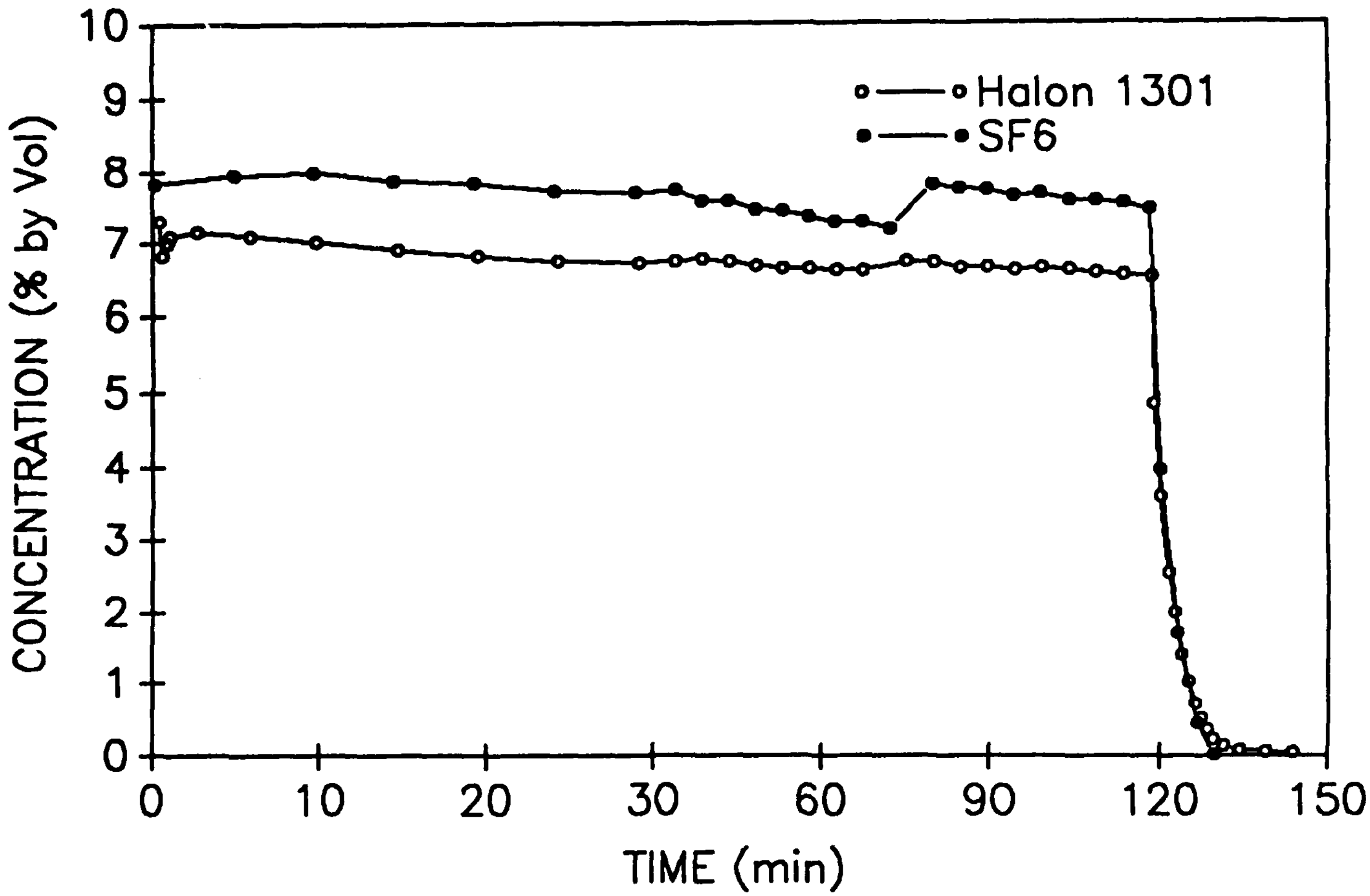

Fig. 39 – Concentration at analyzer point 17

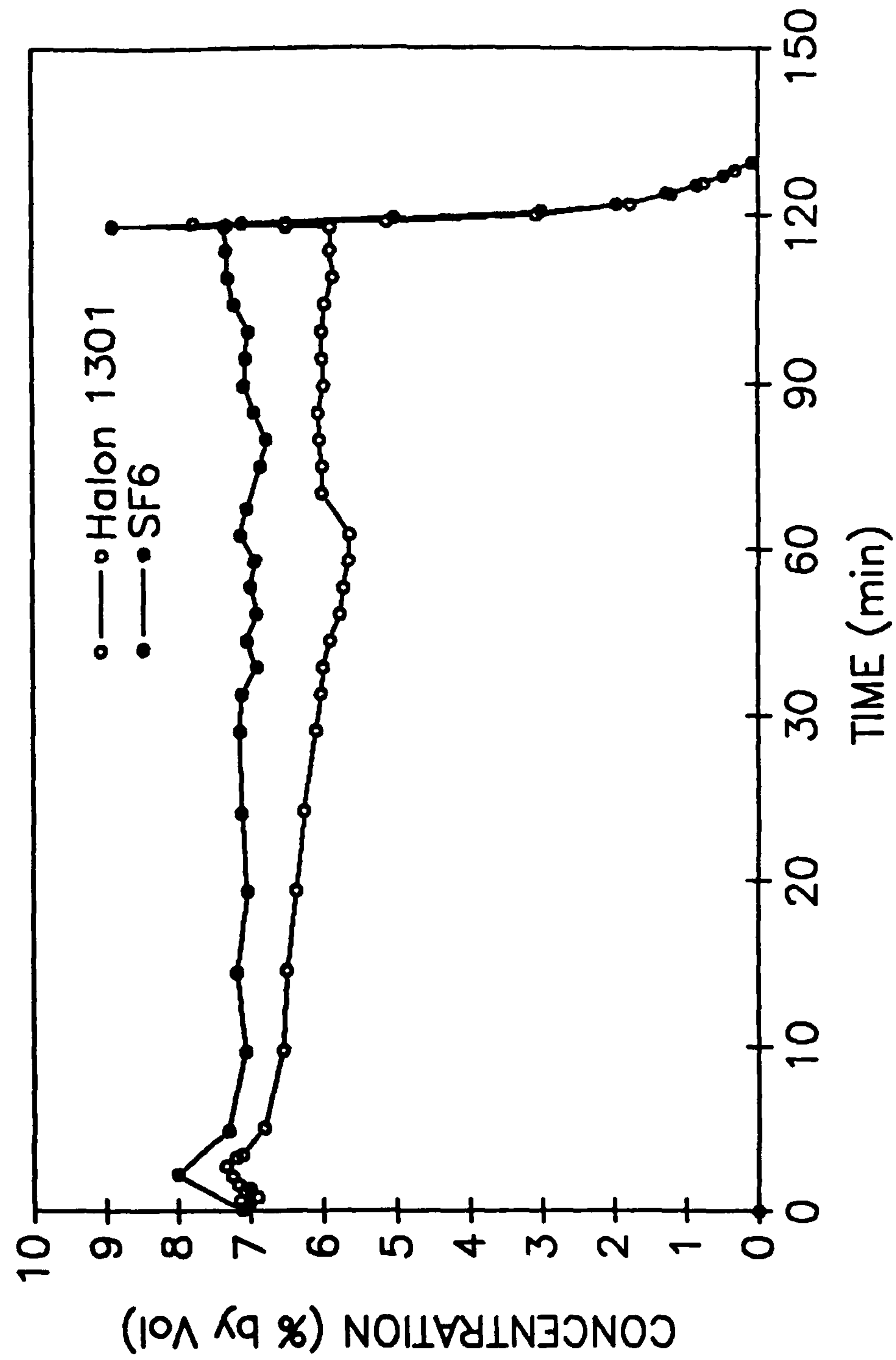

Fig. 40 — Concentration at analyzer point 19

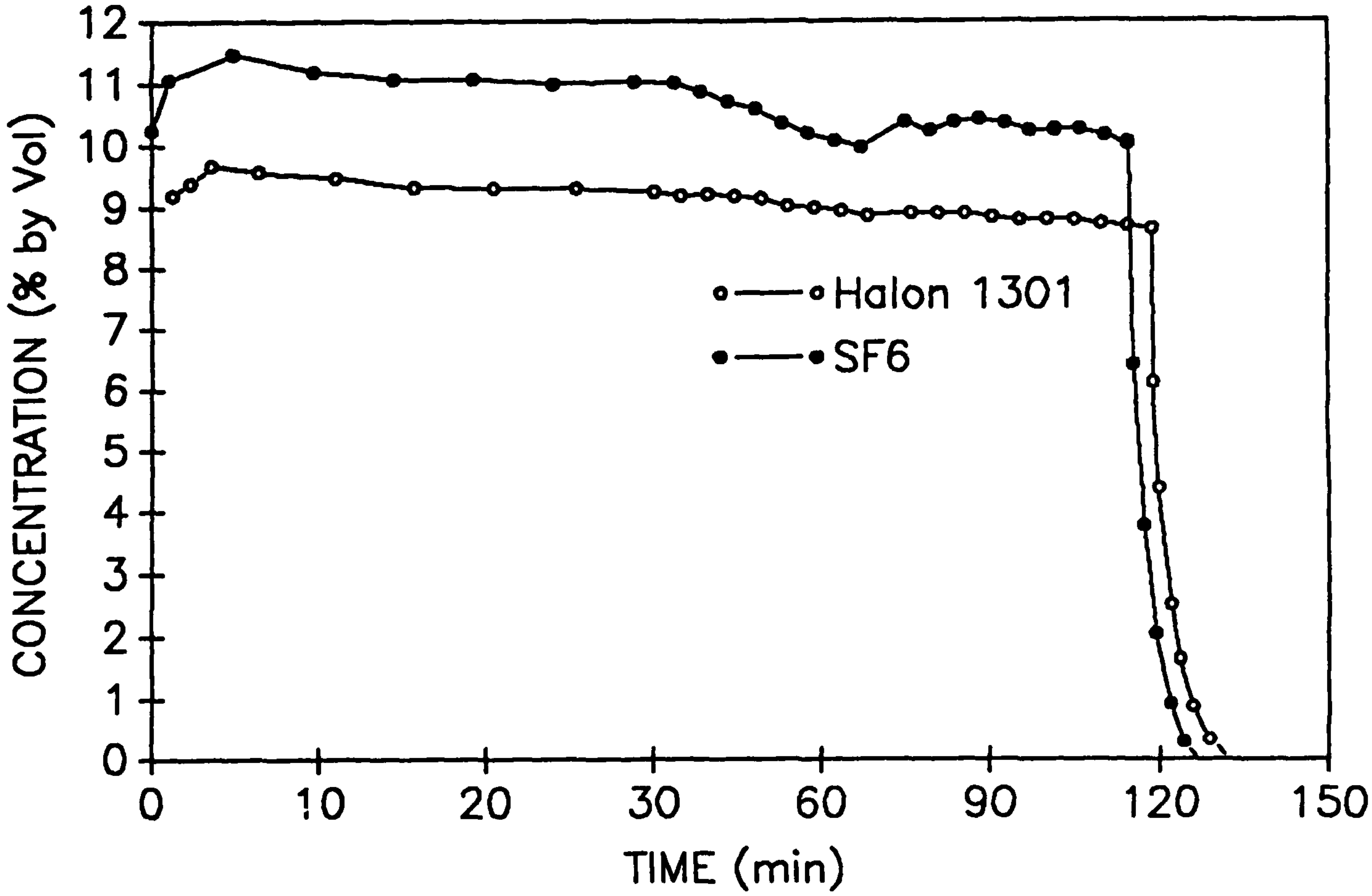

Fig. 41 — Concentration at analyzer point 20

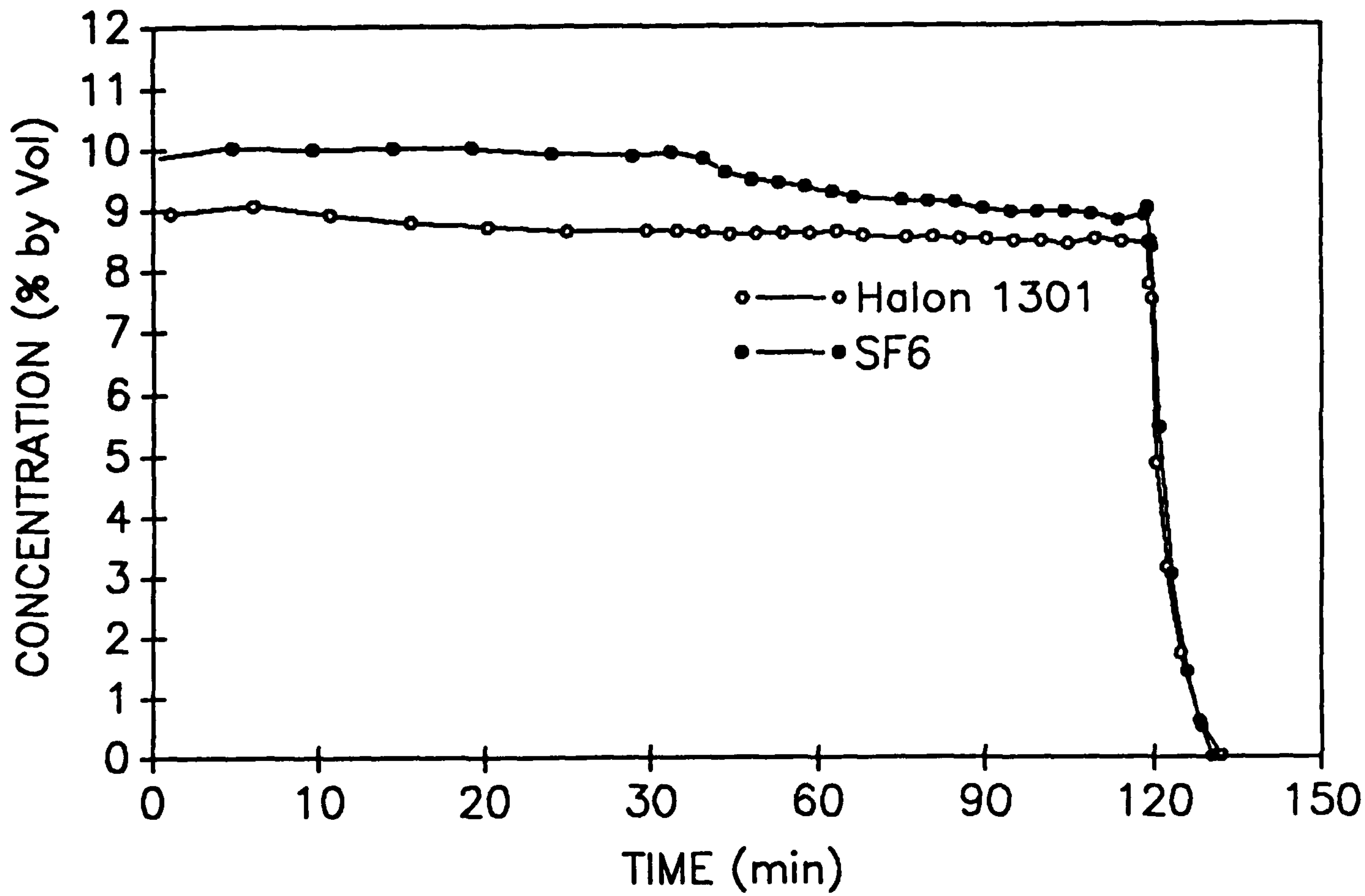

Fig. 42 — Concentration at analyzer point 21

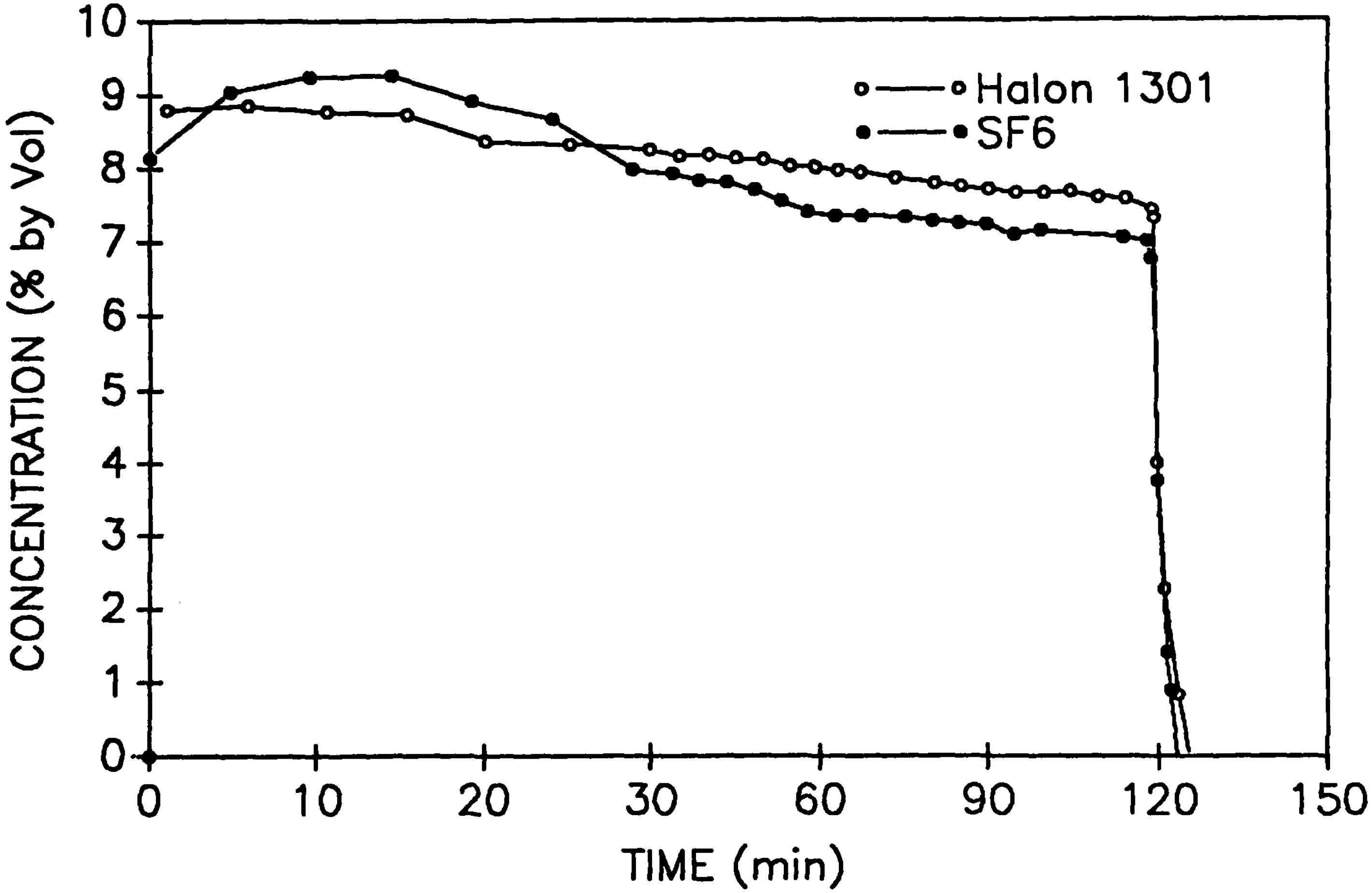

Fig. 43 — Concentration at analyzer point 22

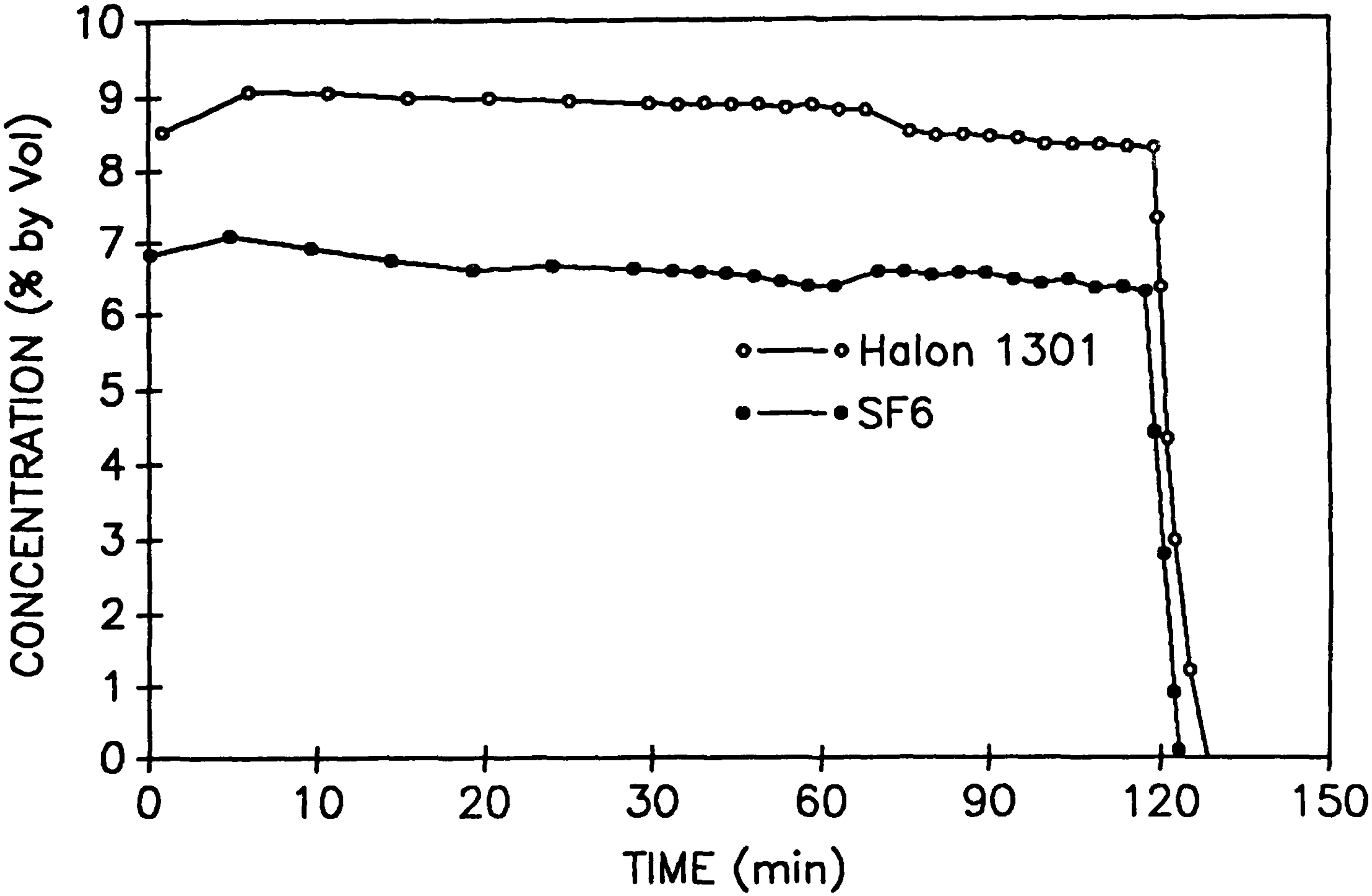

Fig. 44 — Concentration at analyzer point 24

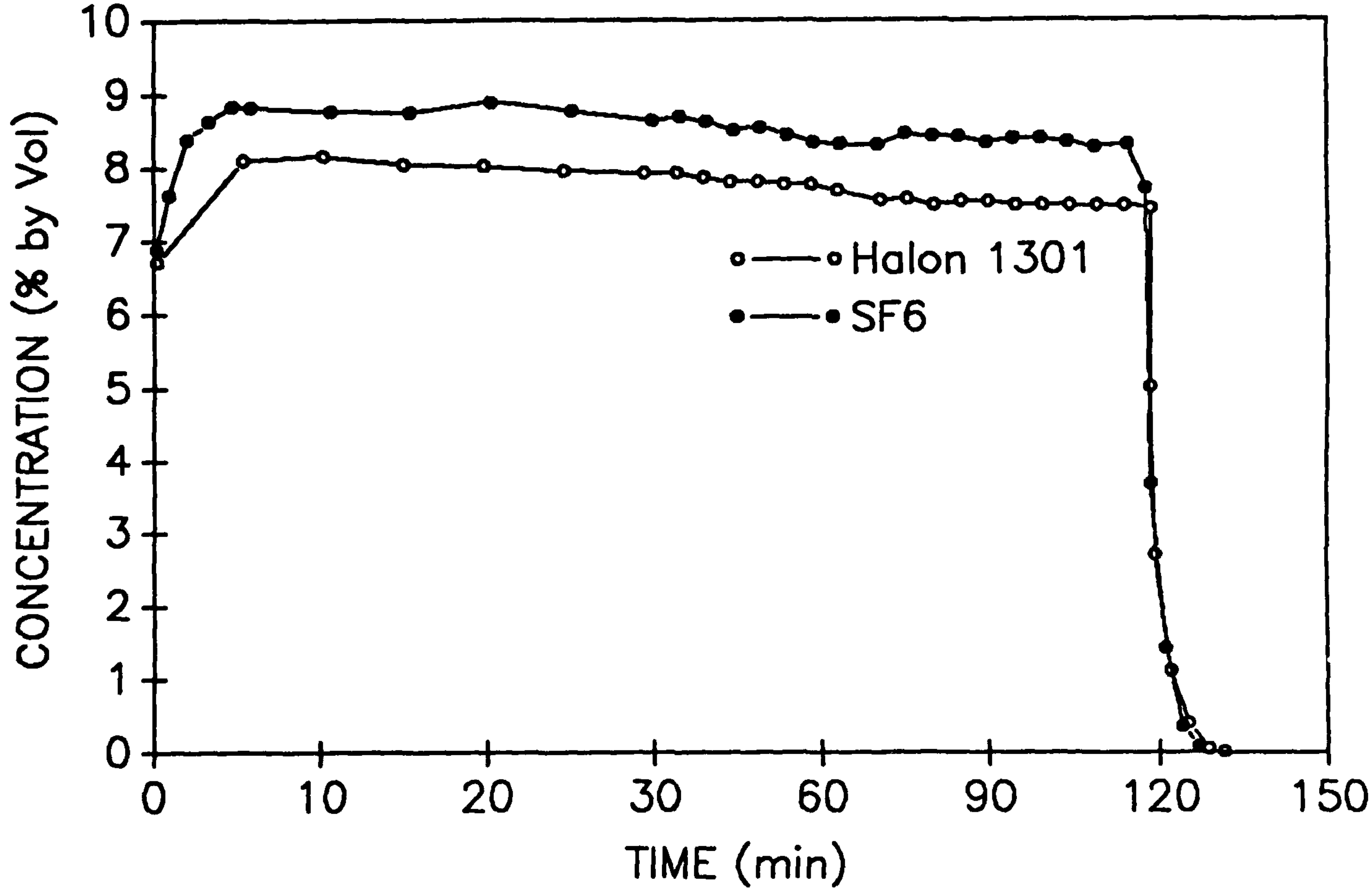

Fig. 45 — Concentration at analyzer point 25

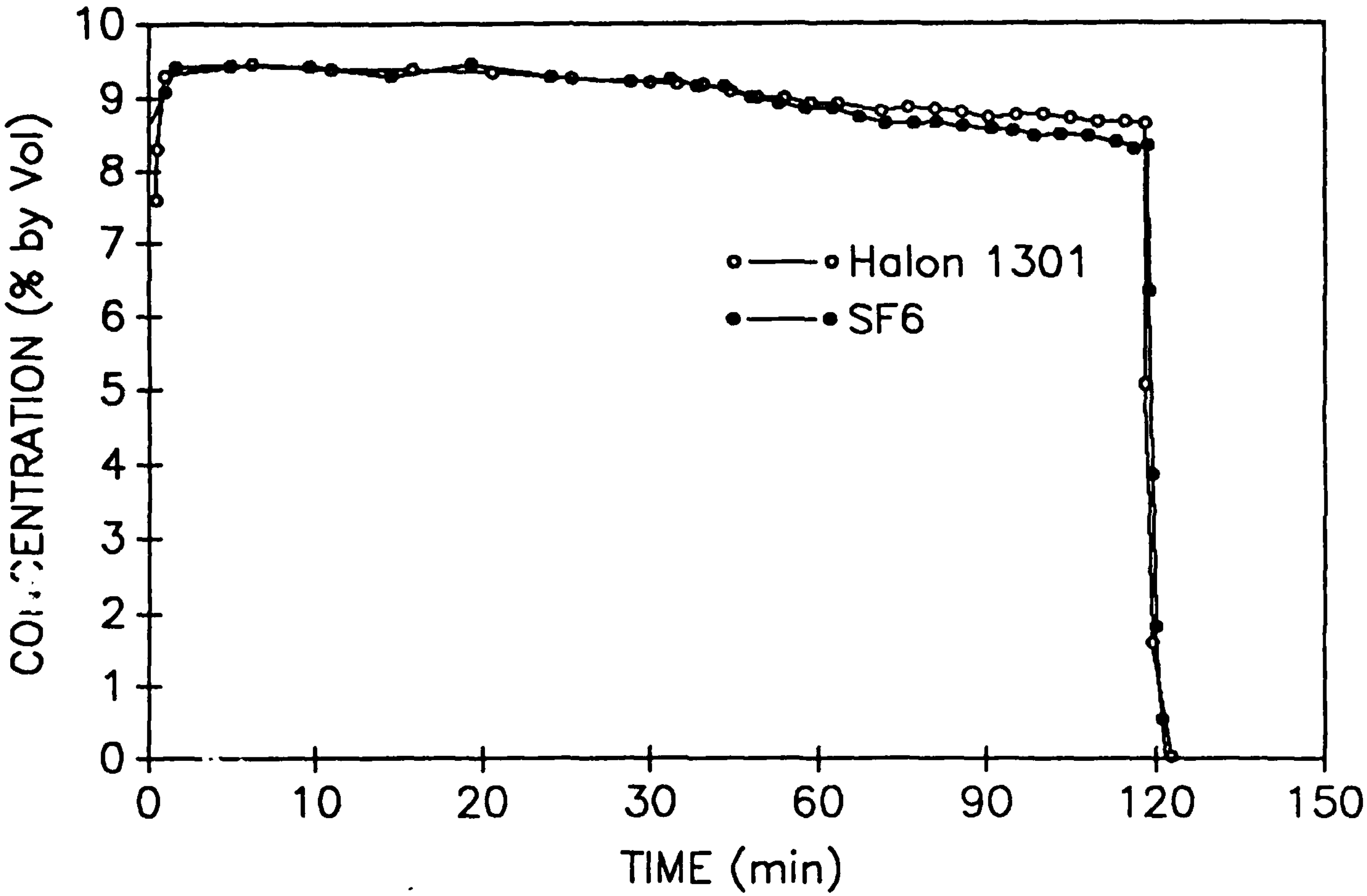

Fig. 46 – Concentration at analyzer point 26

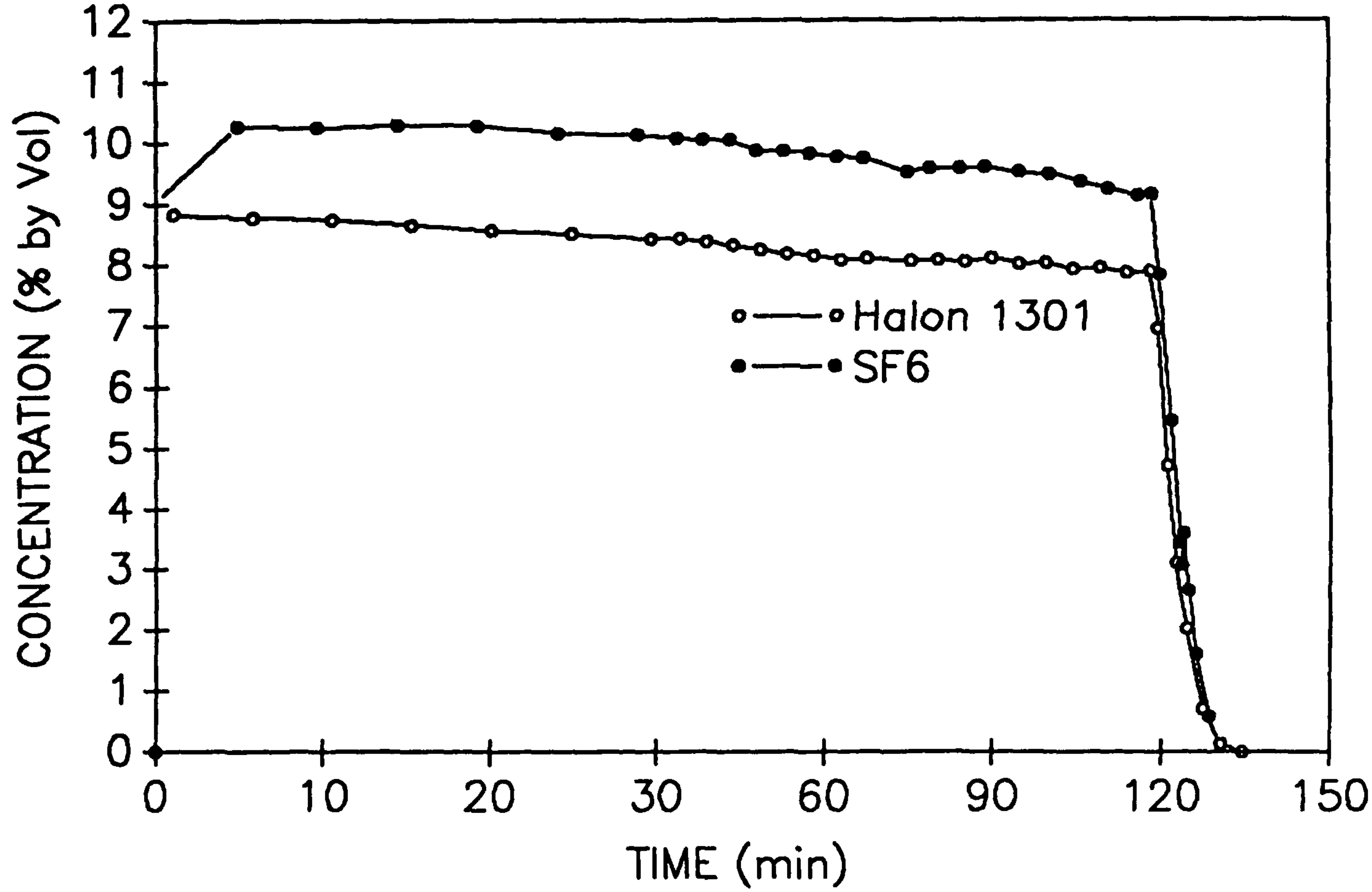

Fig. 47 – Concentration at analyzer point 28

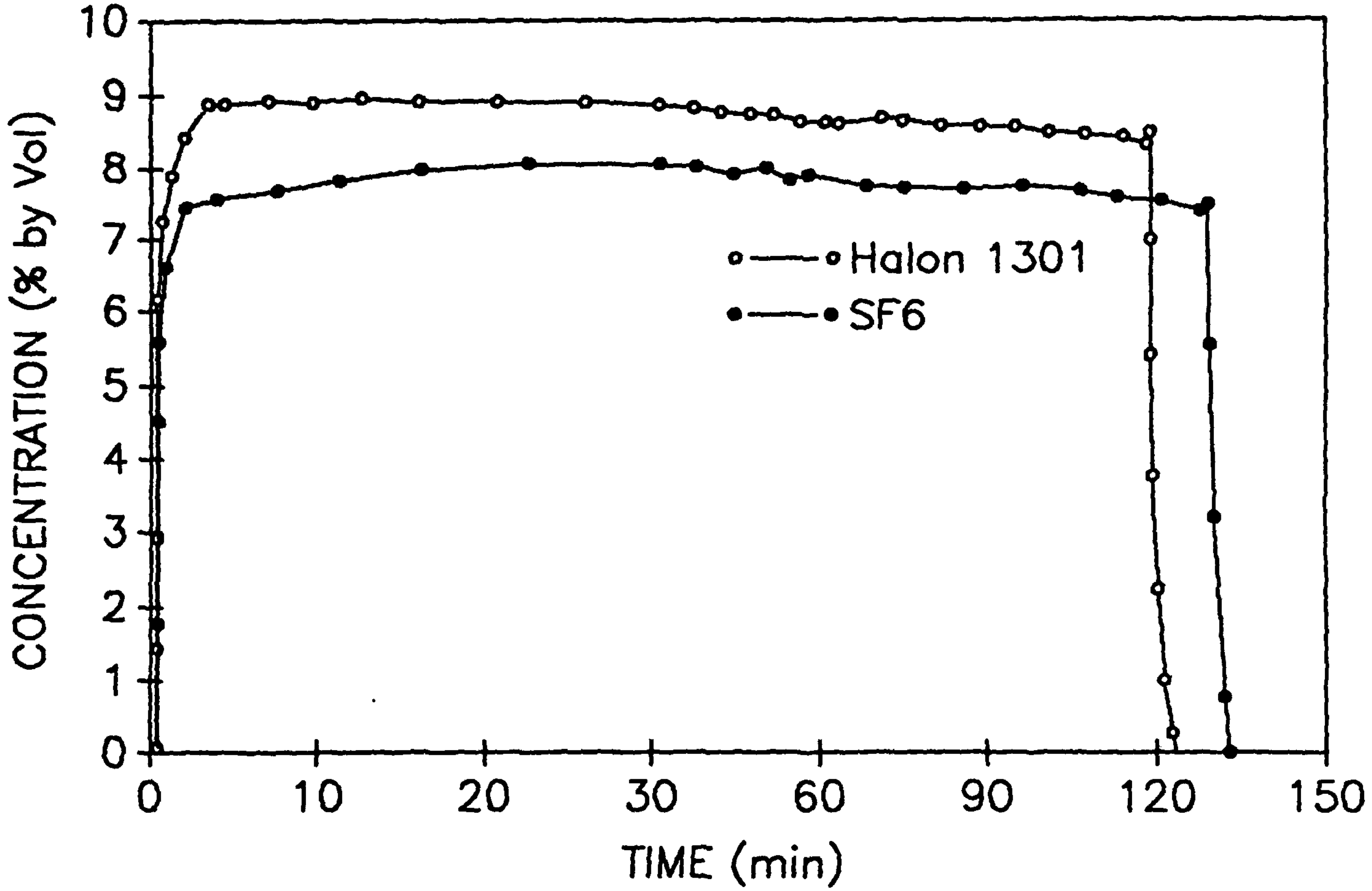

Fig. 48 — Concentration at analyzer point 29

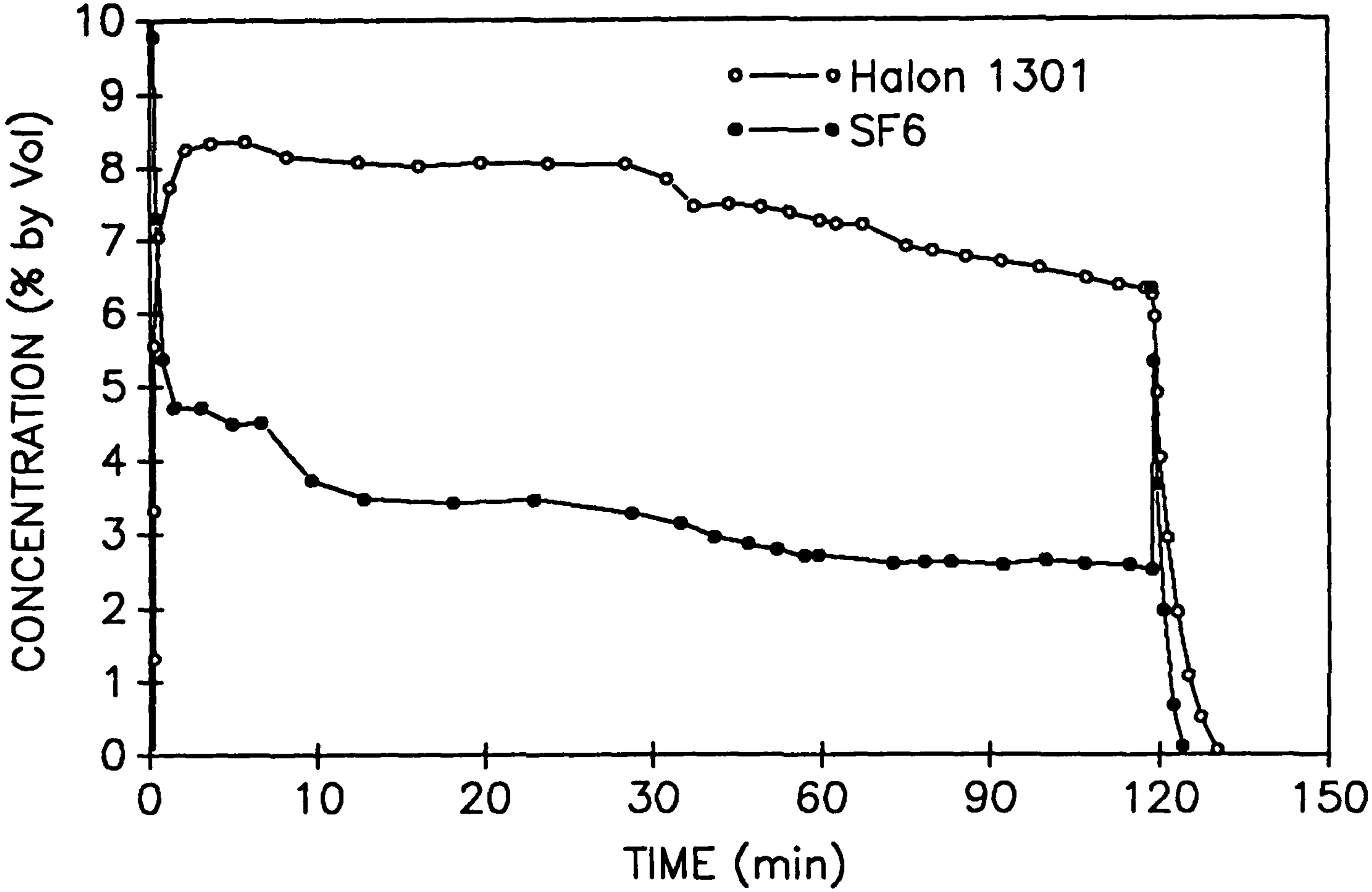

Fig. 49 — Concentration at analyzer point 30
Note: Point 30 was moved between tests

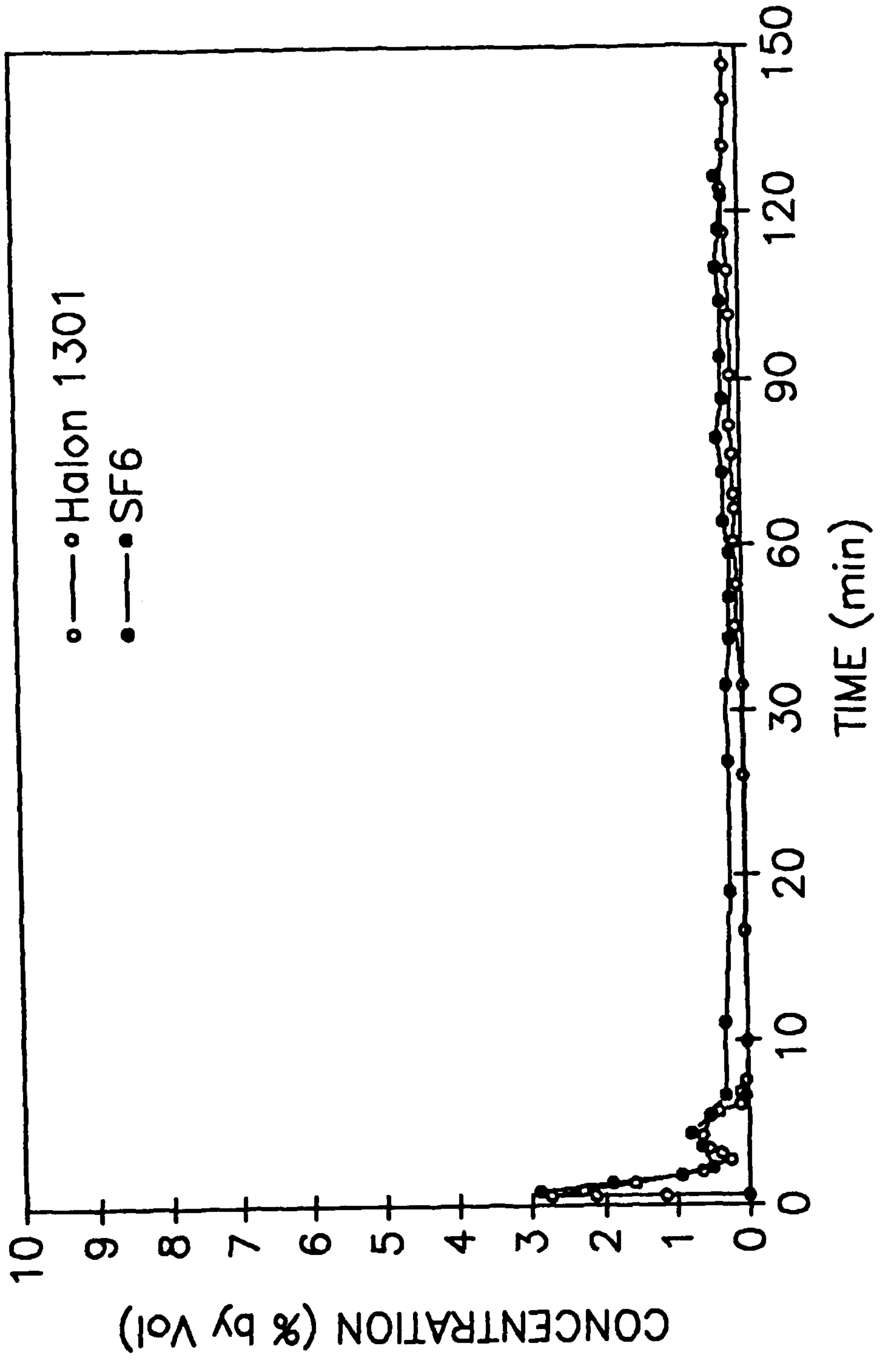

Fig. 50 — Concentration at analyzer point supply 1

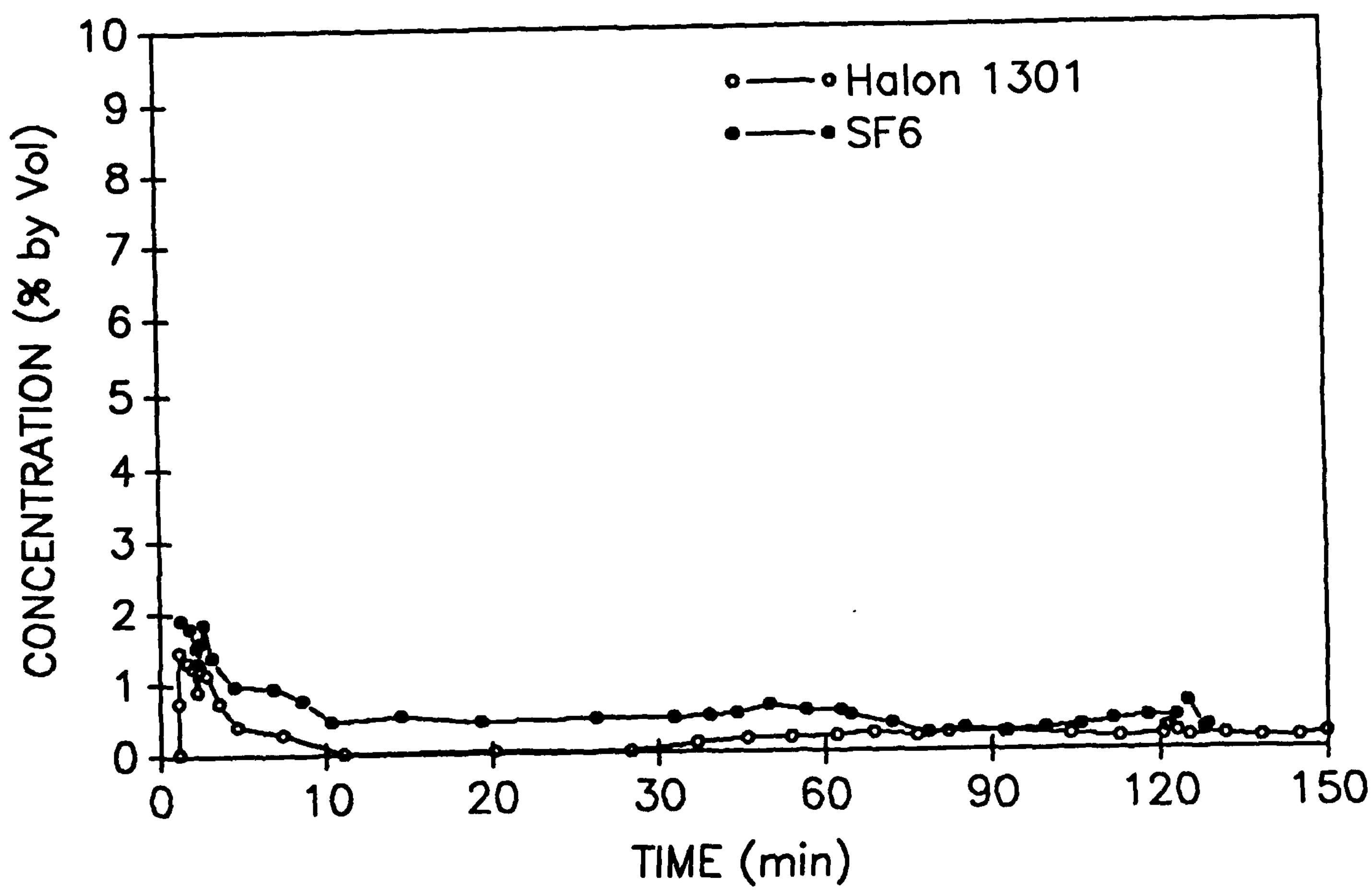

Fig. 51 – Concentration at analyzer point supply 2

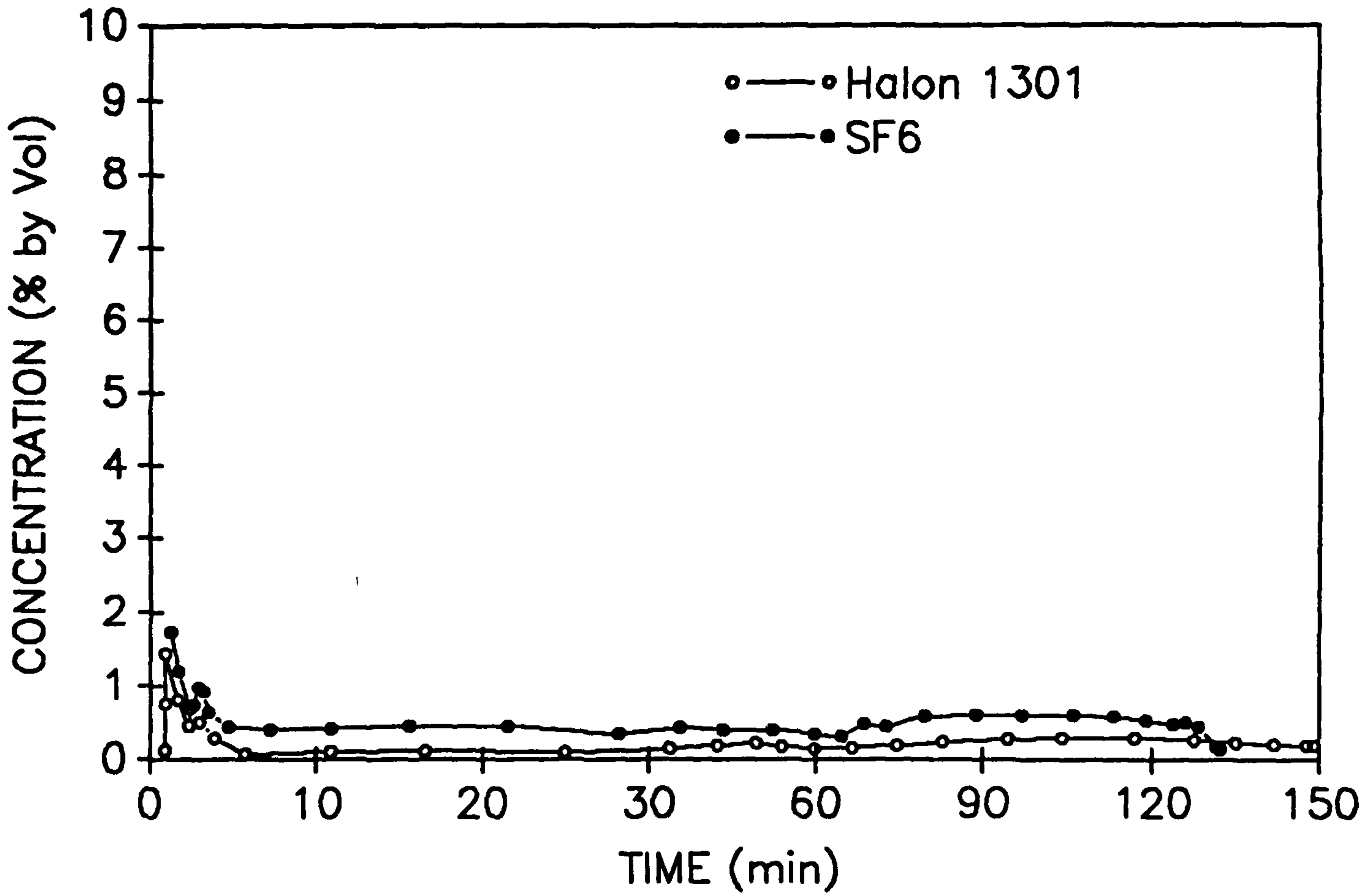

Fig. 52 — Concentration at analyzer point supply 3

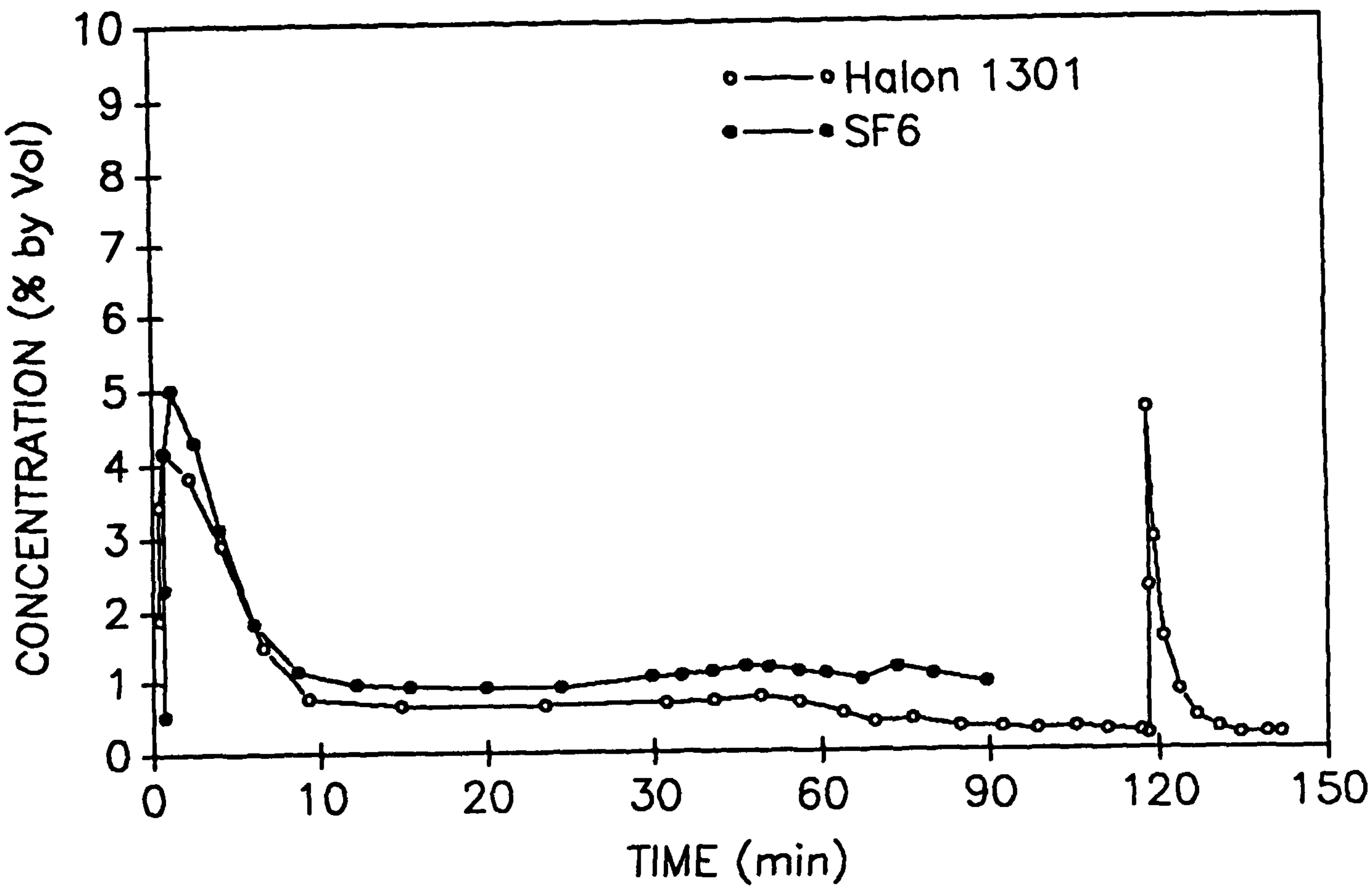

Fig. 53 — Concentration at analyzer point exhaust 1

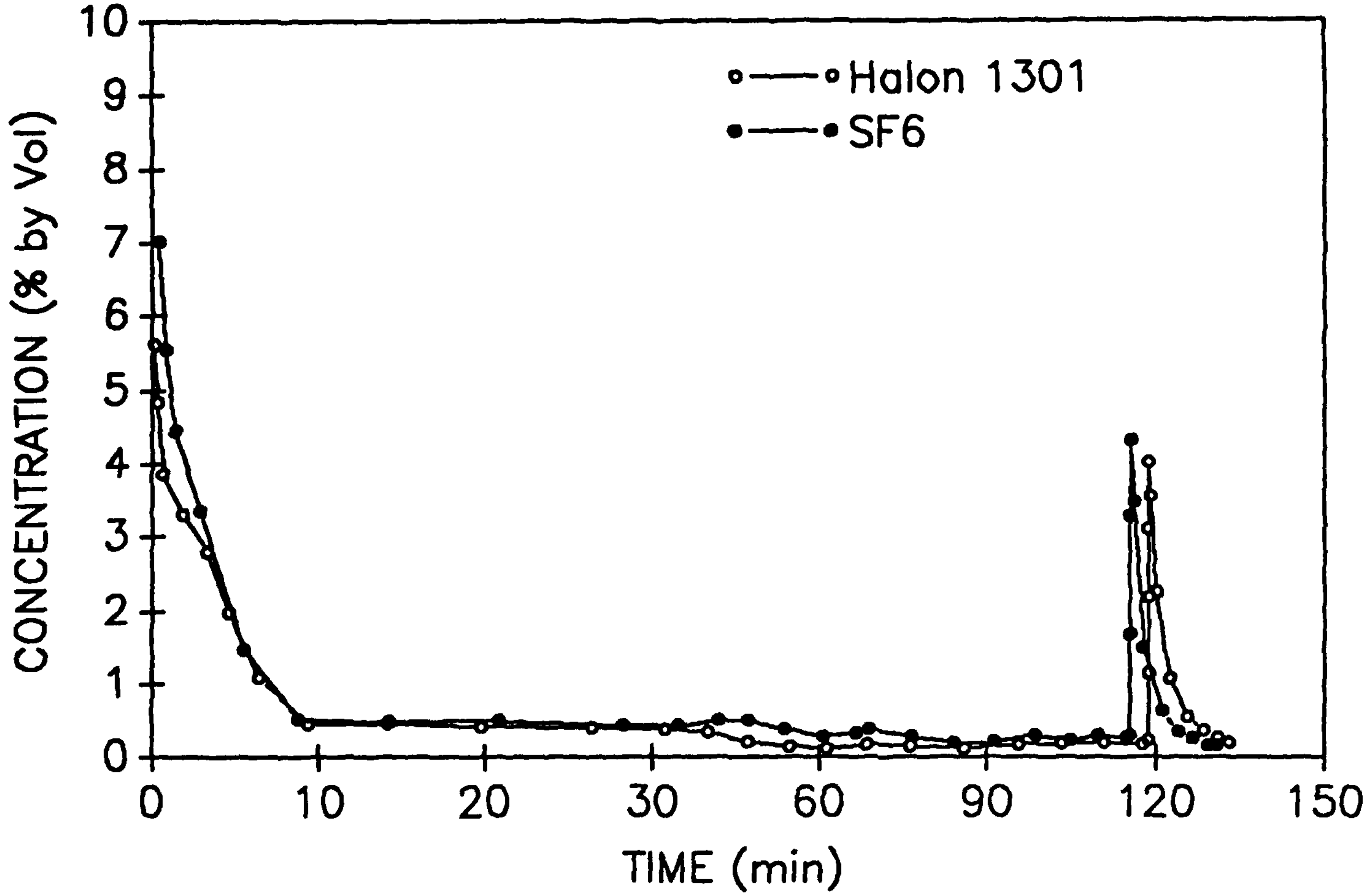

Fig. 54 — Concentration at analyzer point exhaust 2

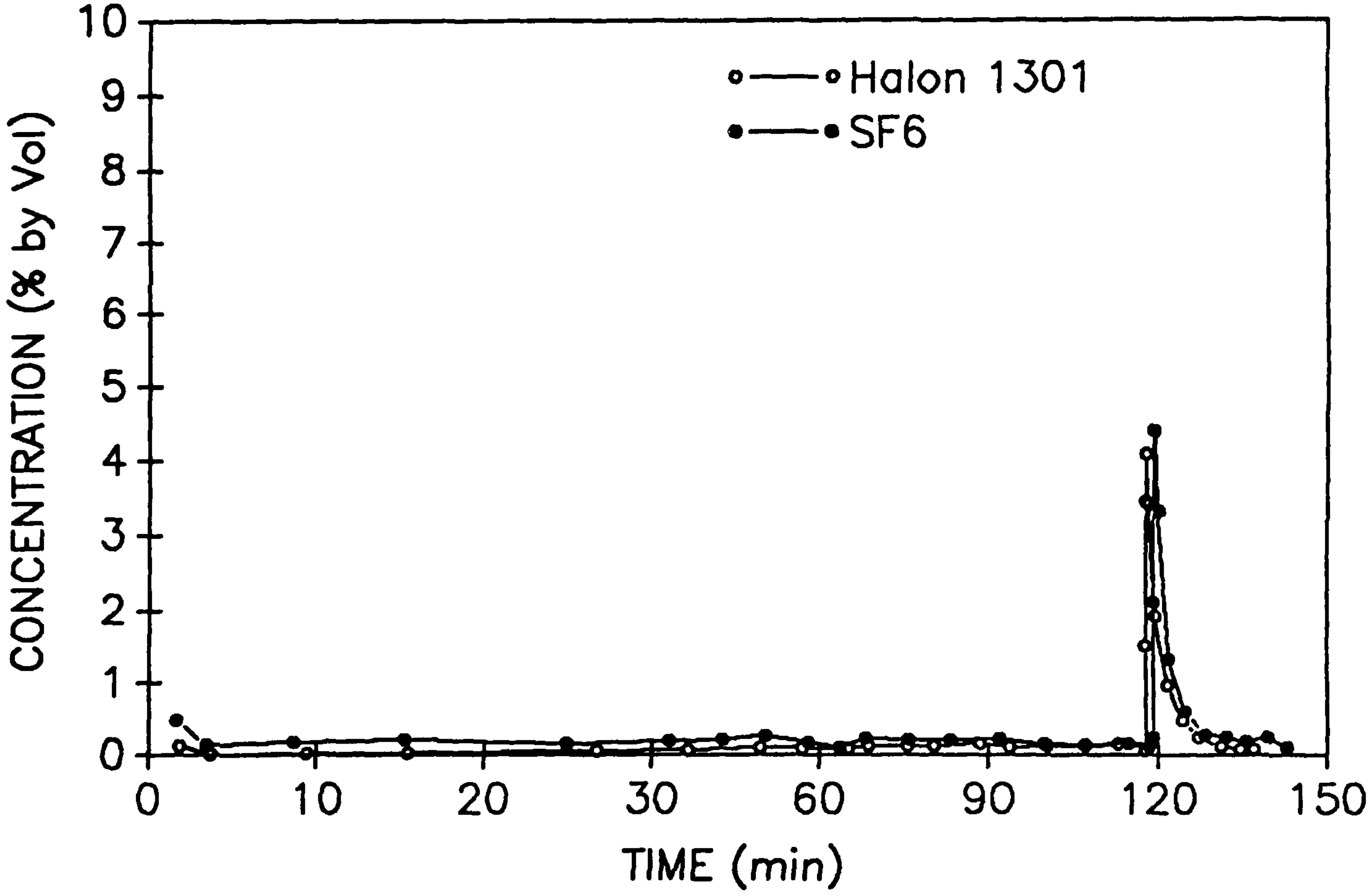

Fig. 55 — Concentration at analyzer point exhaust 3

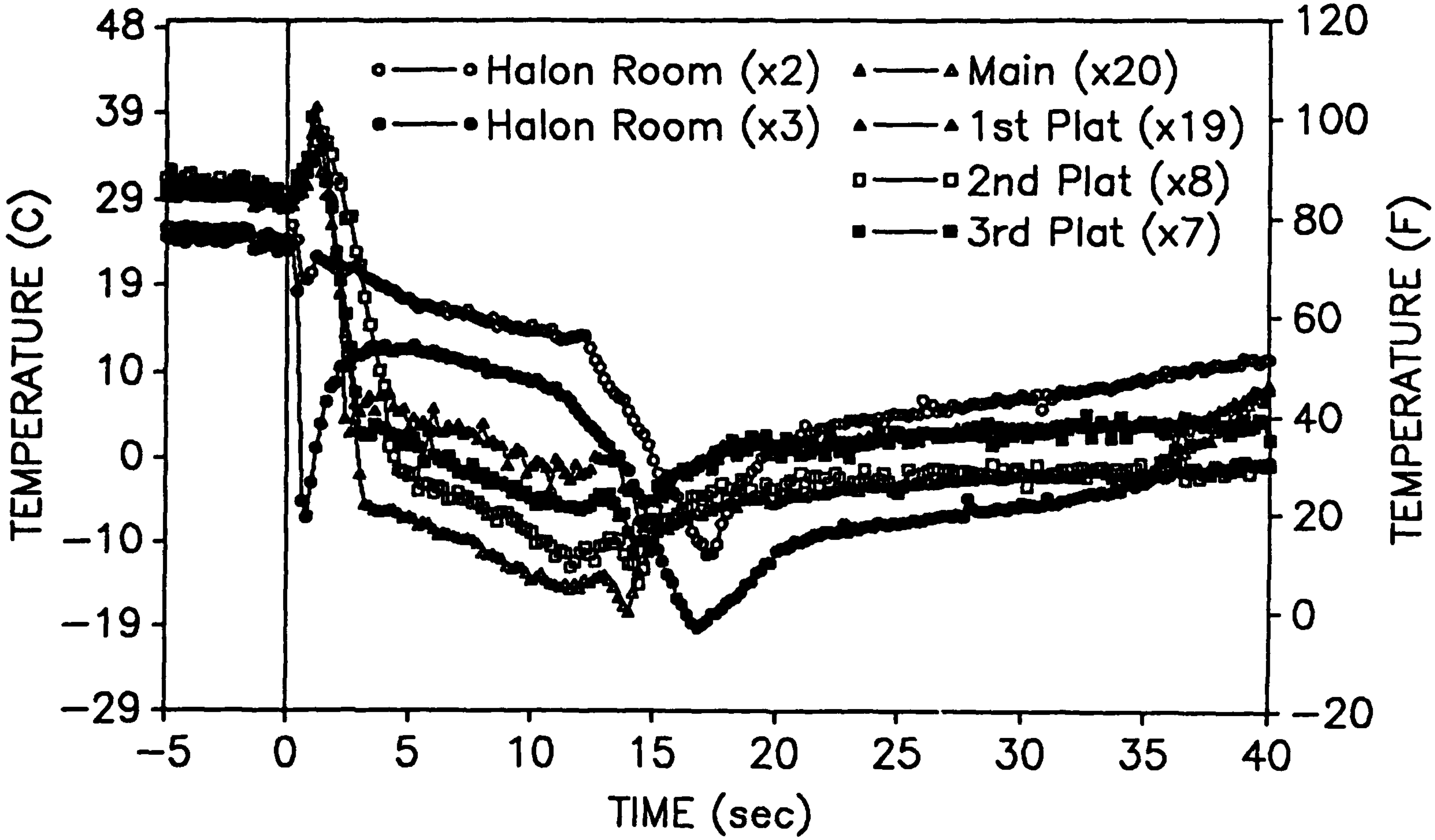

Fig. 56 — Temperature of flowing Halon 1301 at representative locations

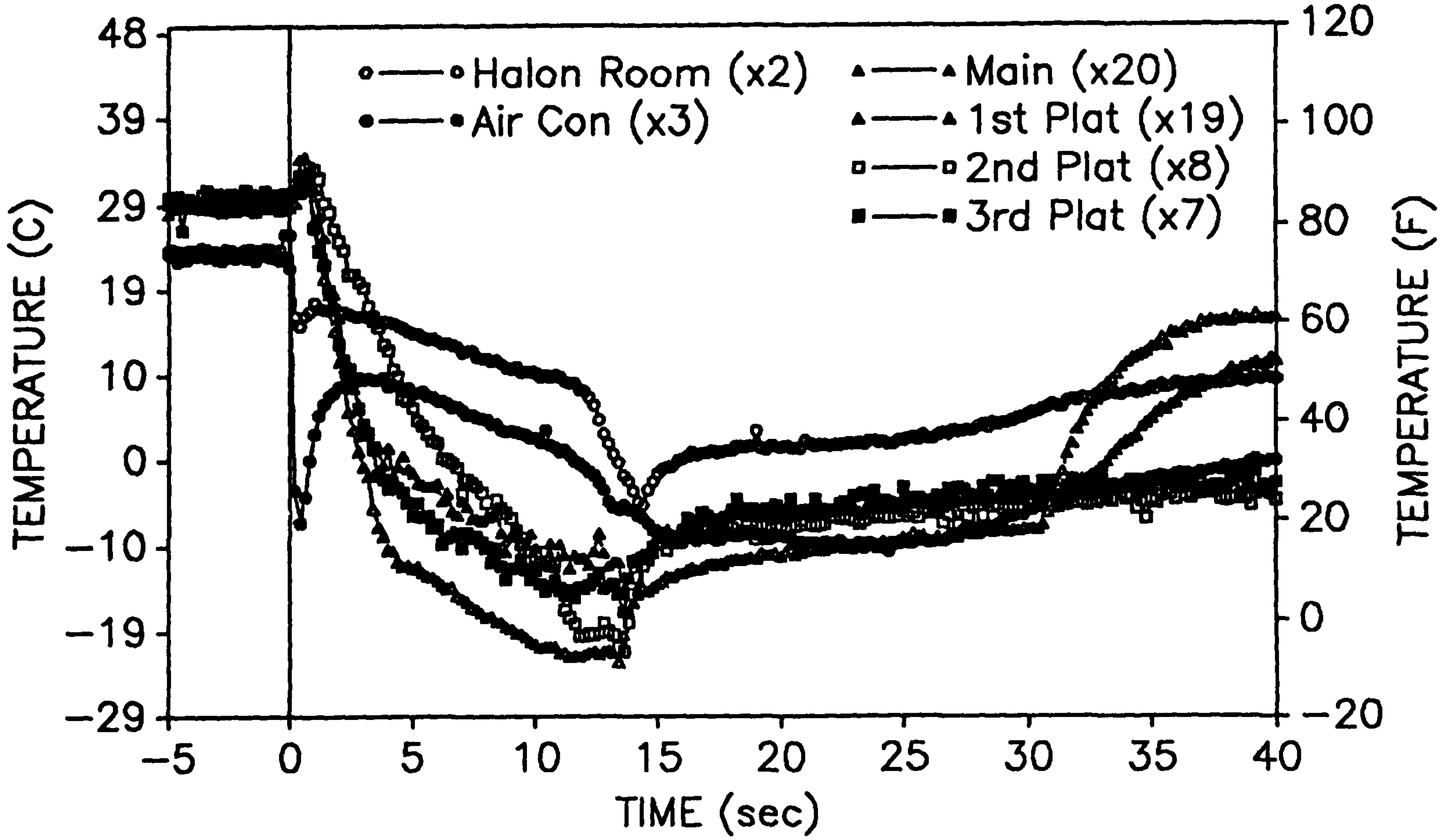

Fig. 57 — Temperature of flowing sulfur hexafluoride at representative locations

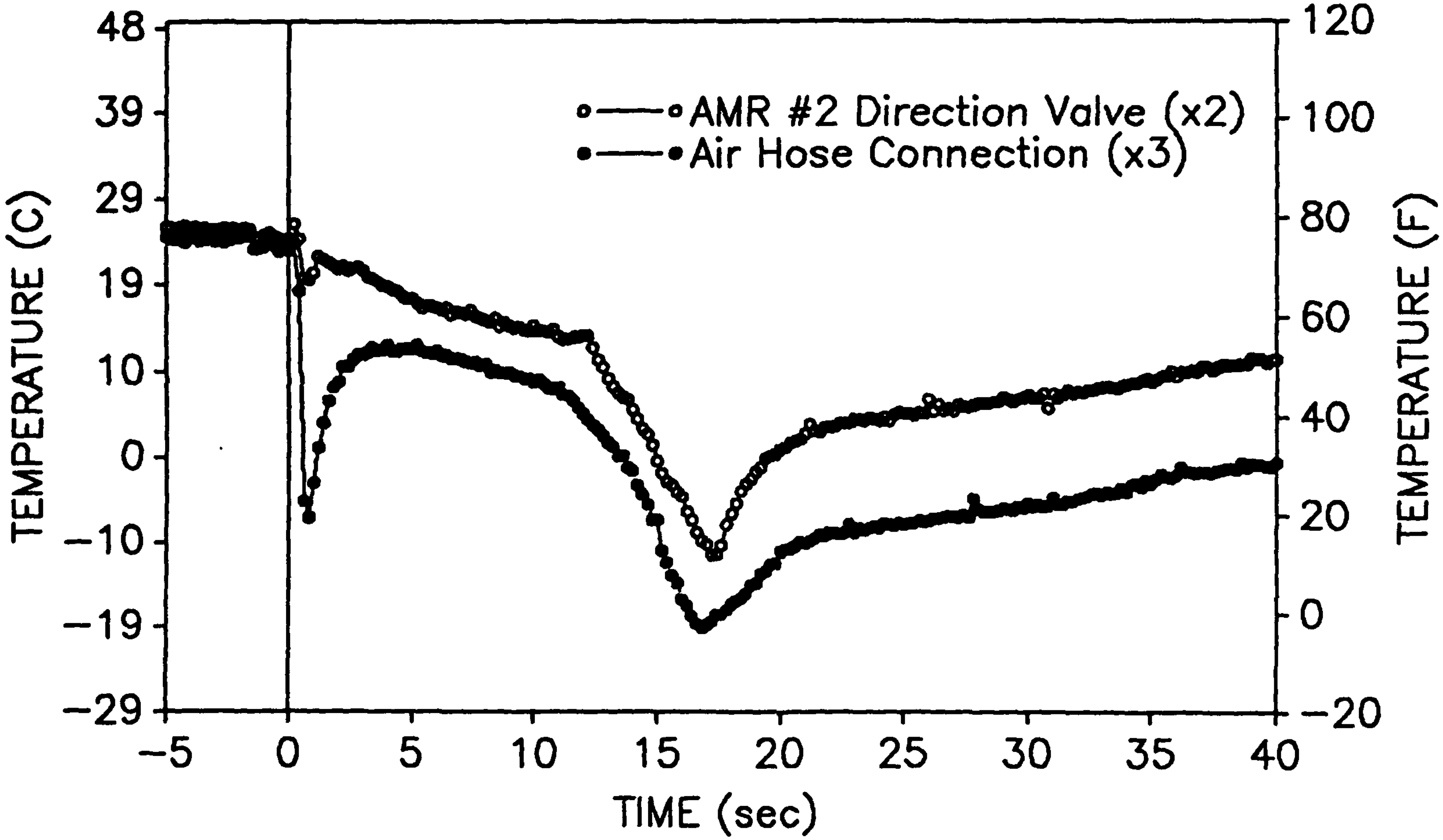

Fig. 58 — Temperature of flowing Halon 1301 at halon room fittings

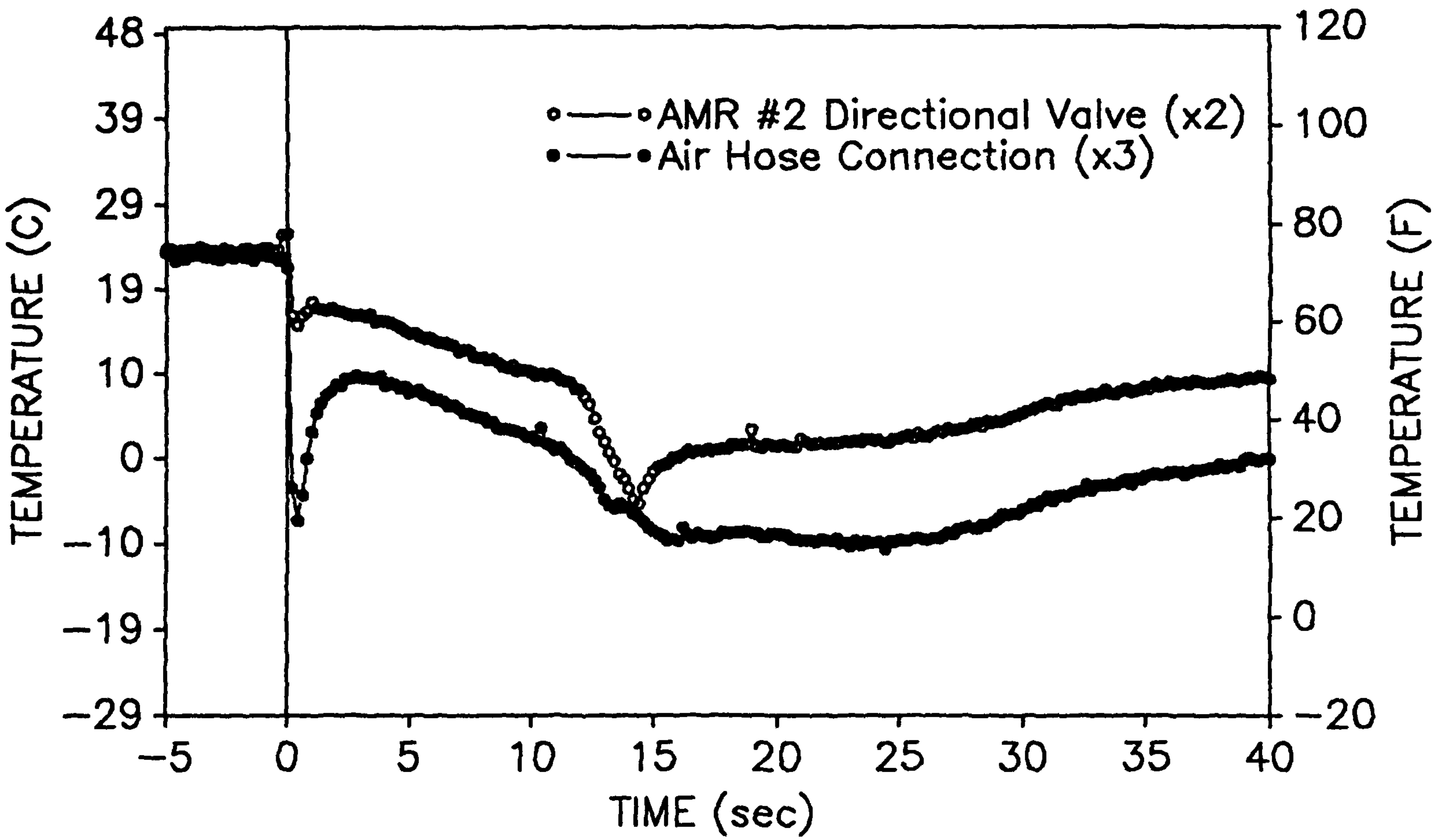

Fig. 59 — Temperature of flowing sulfur hexafluoride at halon room fittings

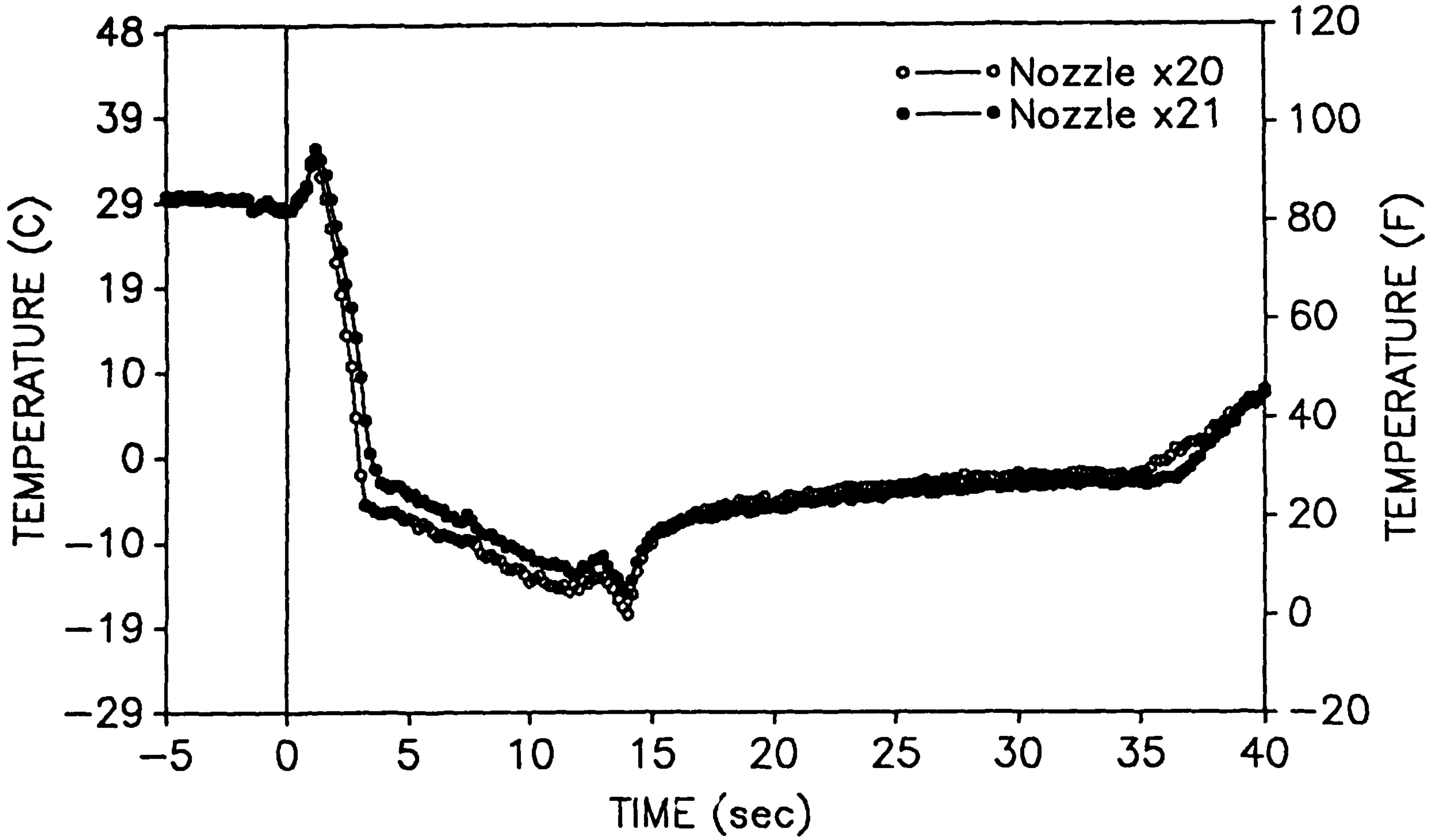

Fig. 60 – Temperature of flowing Halon 1301 through main deck nozzles

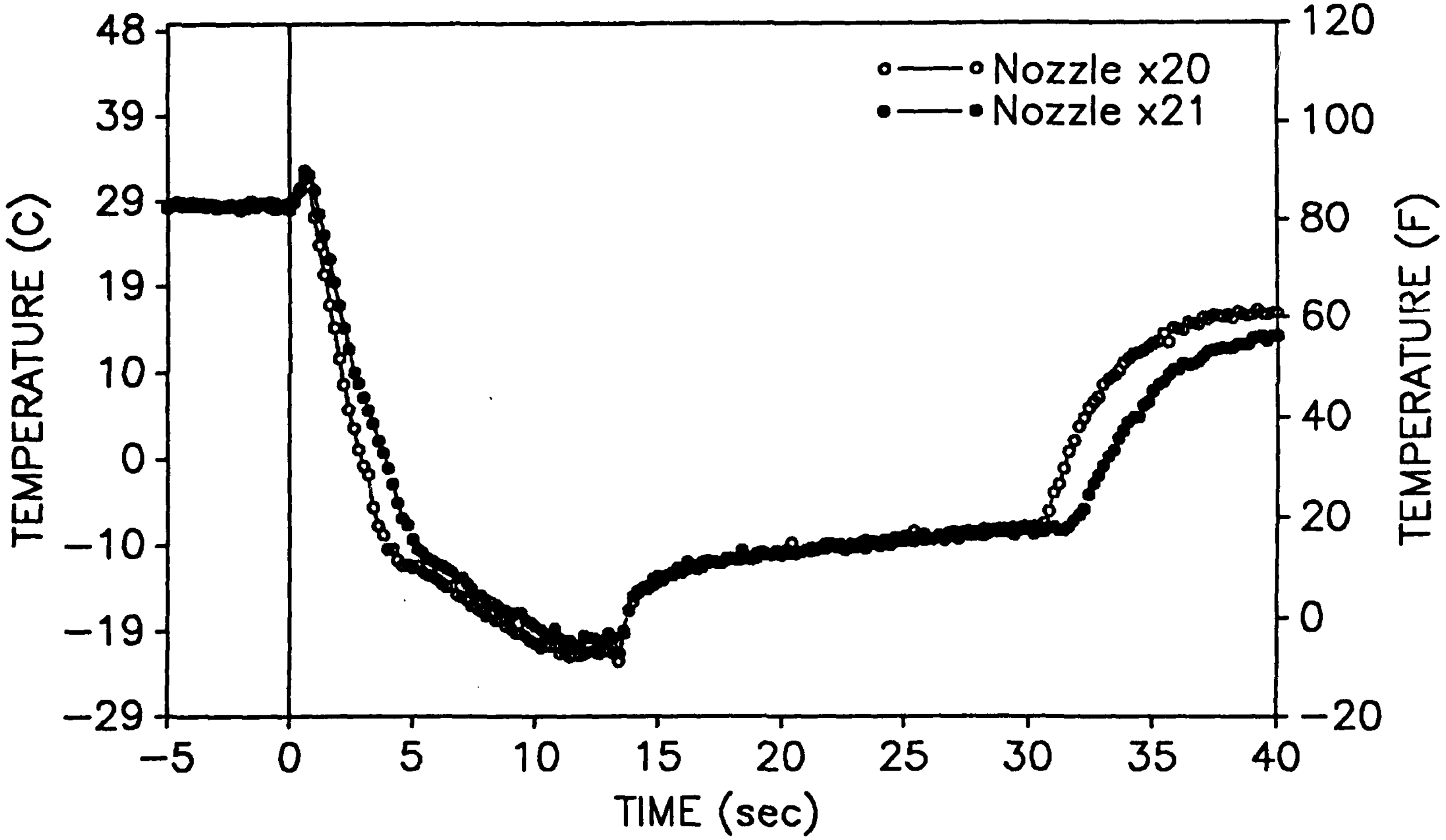

Fig. 61 — Temperature of flowing sulfur hexafluoride through main deck nozzles

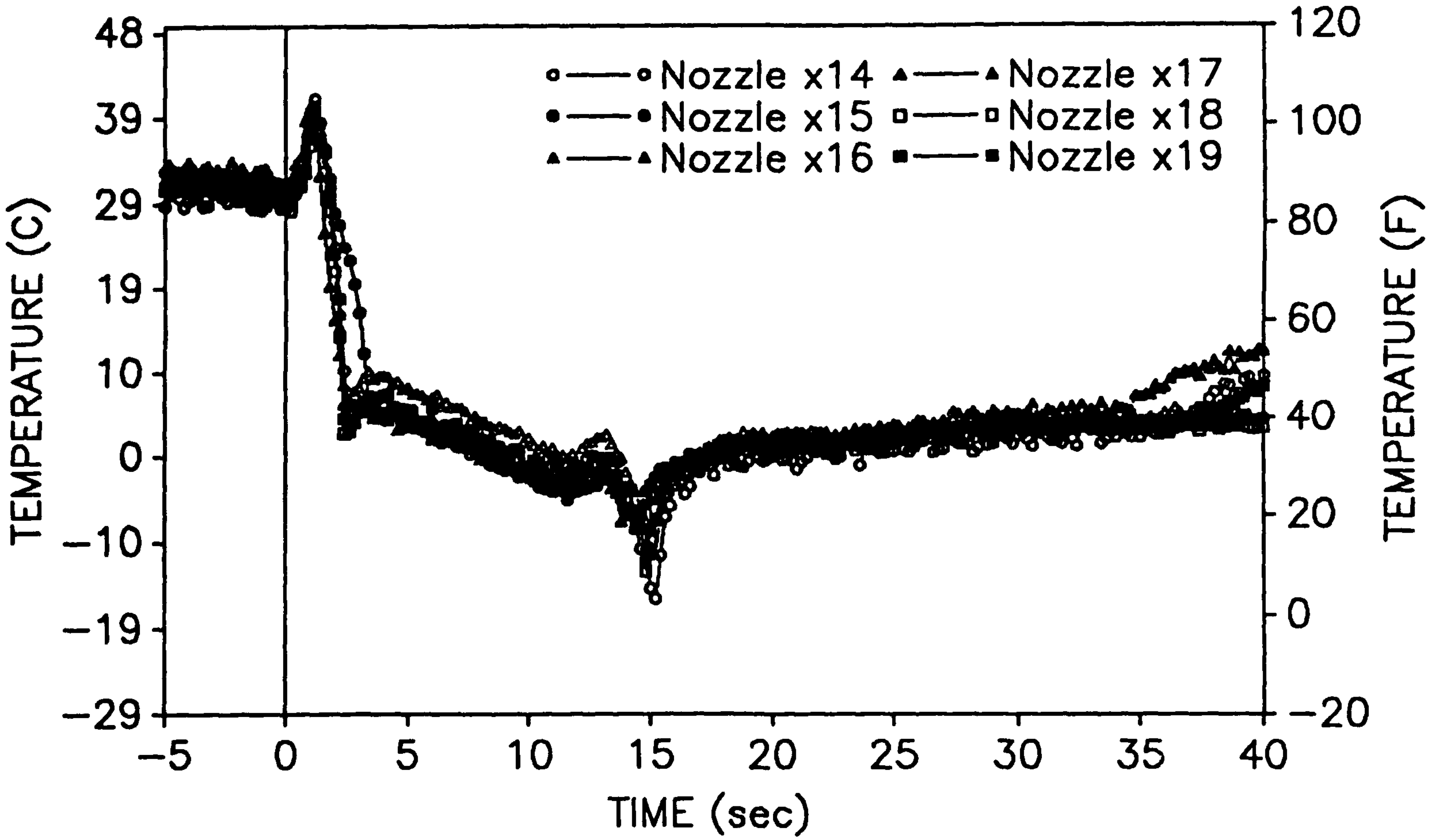

Fig. 62 – Temperature of flowing Halon 1301 through 1st platform nozzles

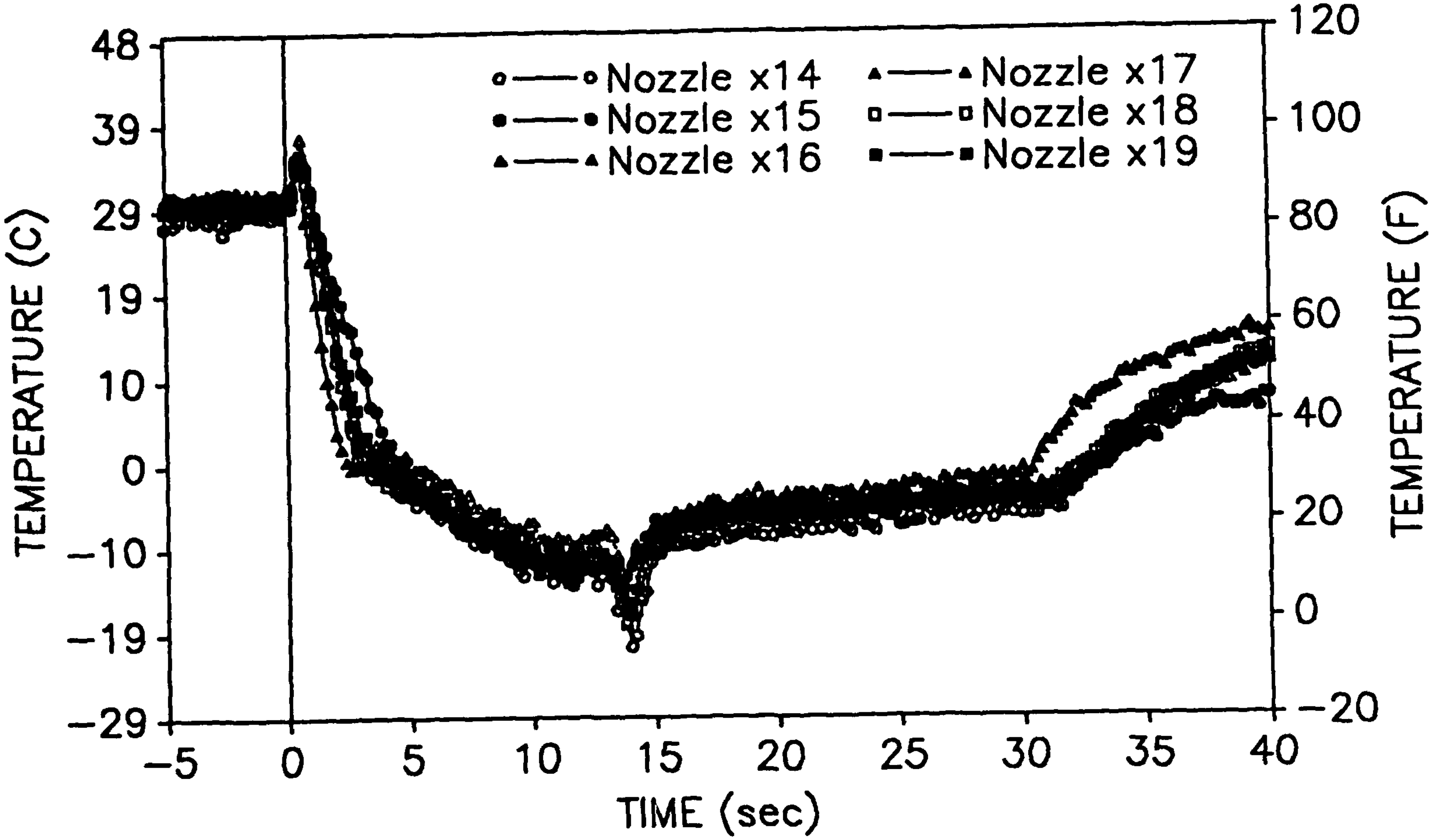

Fig. 63 – Temperature of flowing sulfur hexafluoride through 1st platform nozzles

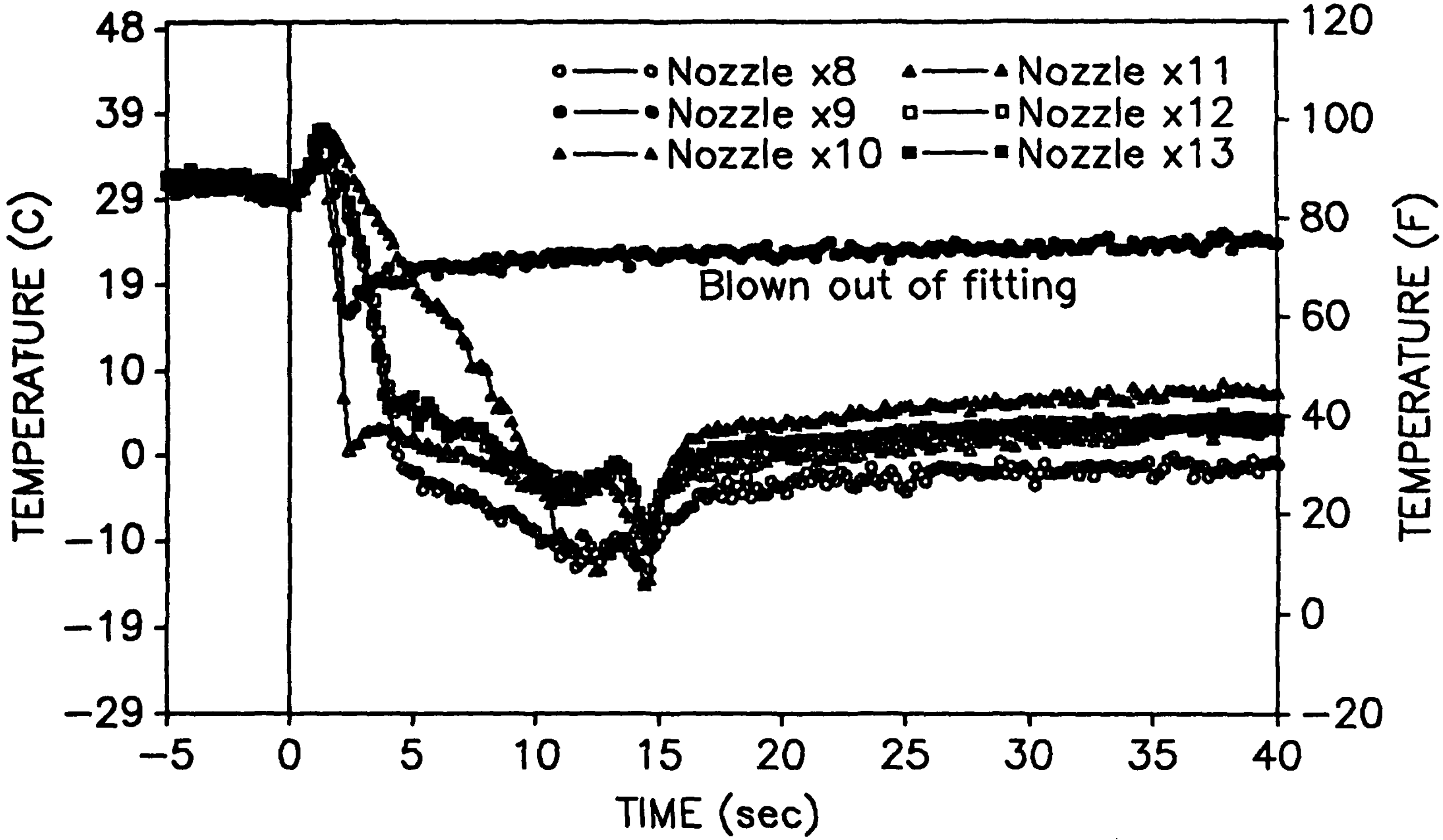

Fig. 64 — Temperature of flowing Halon 1301 through 2nd platform nozzles

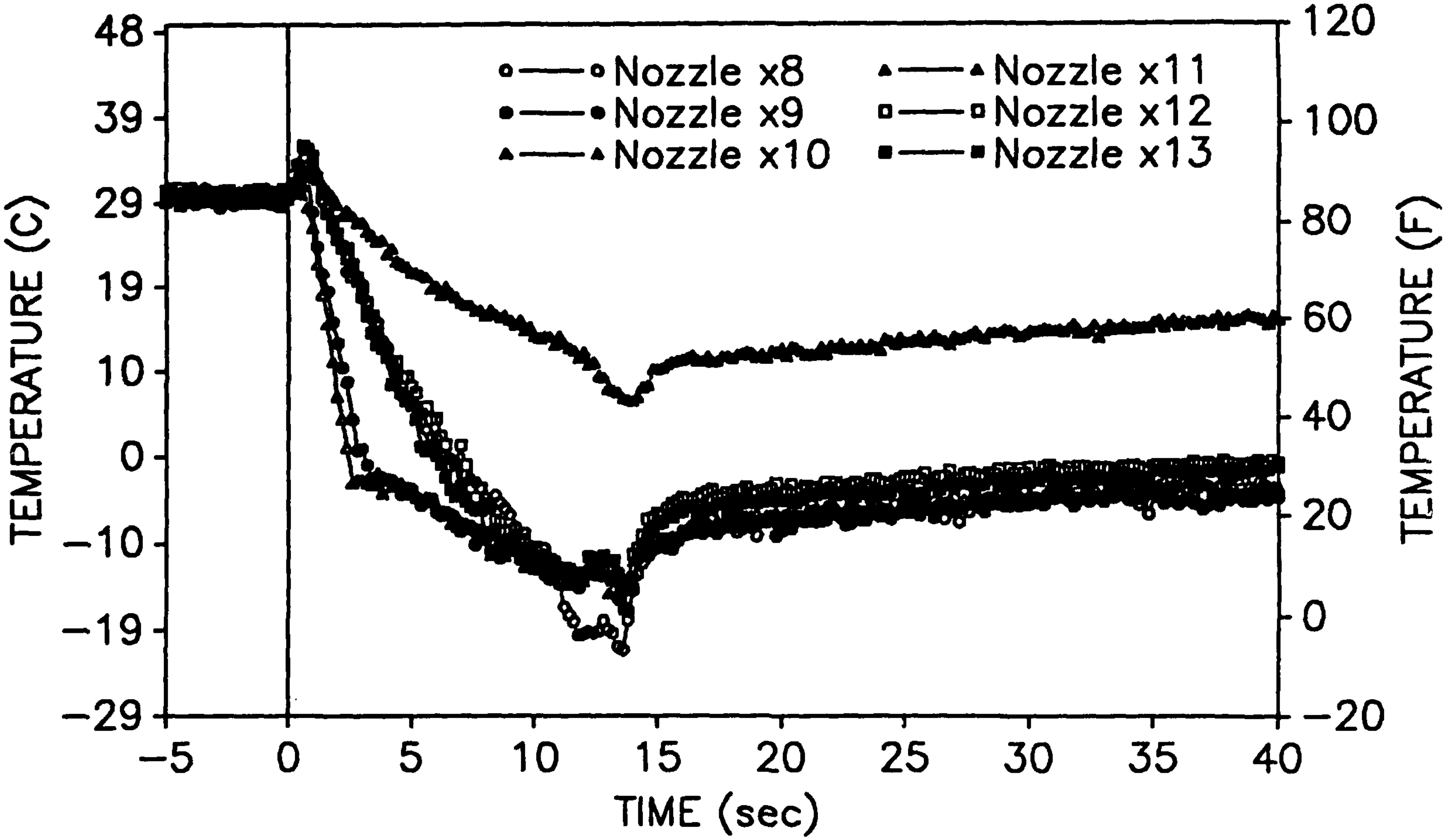

Fig. 65 — Temperature of flowing sulfur hexafluoride through 2nd platform nozzles

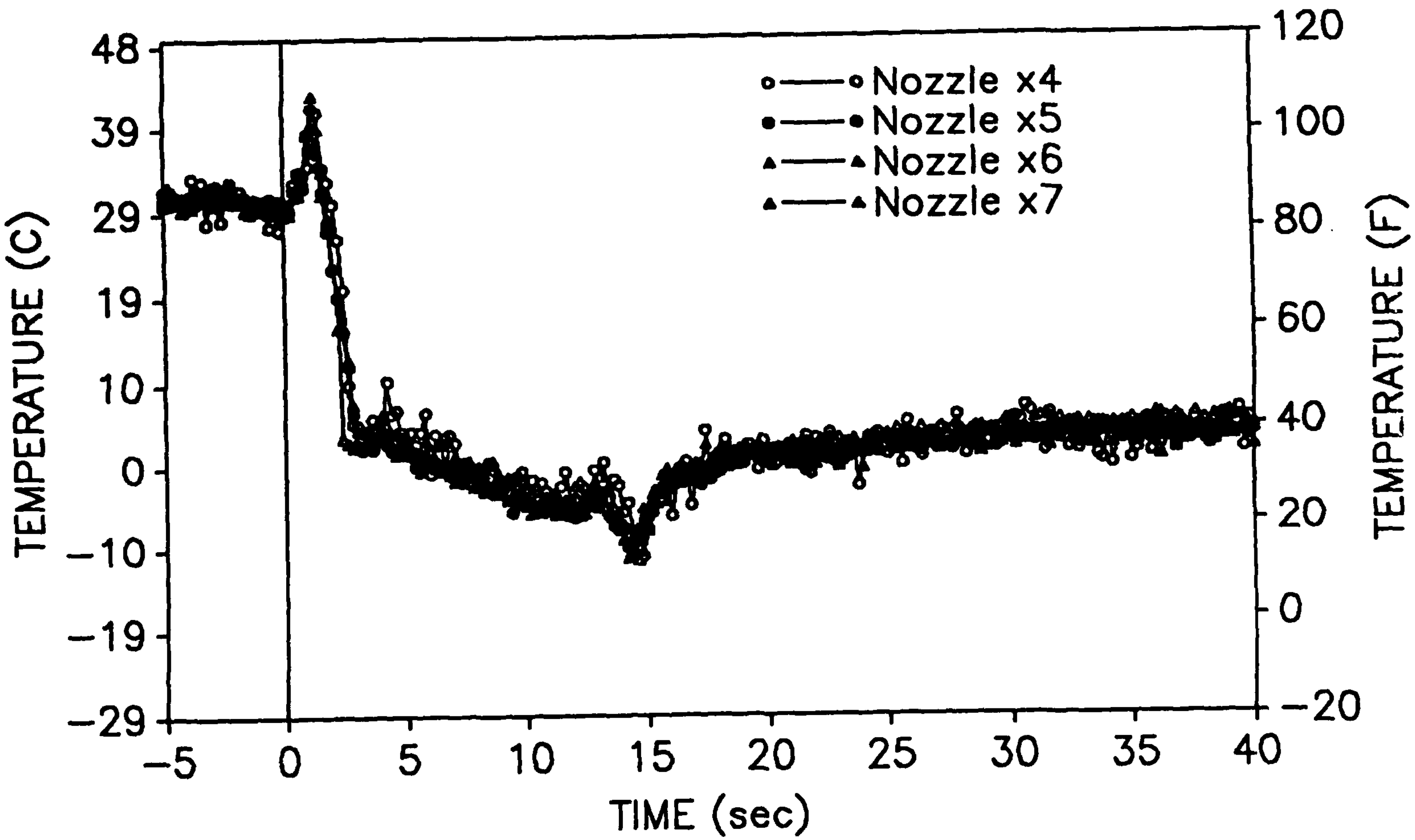

Fig. 66 — Temperature of flowing Halon 1301 through 3rd platform nozzles

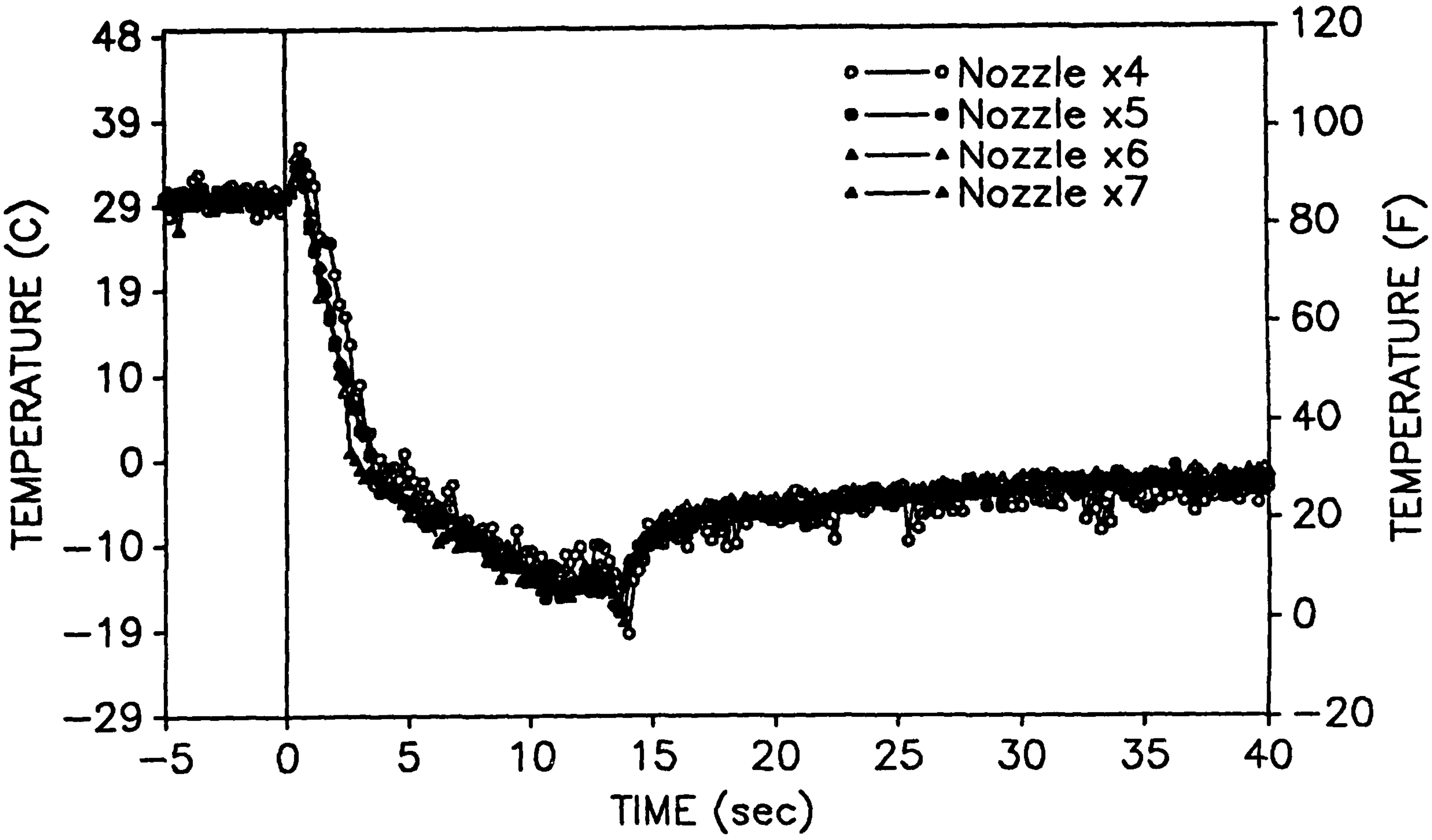

Fig. 67 – Temperature of flowing sulfur hexafluoride through 3rd platform nozzles

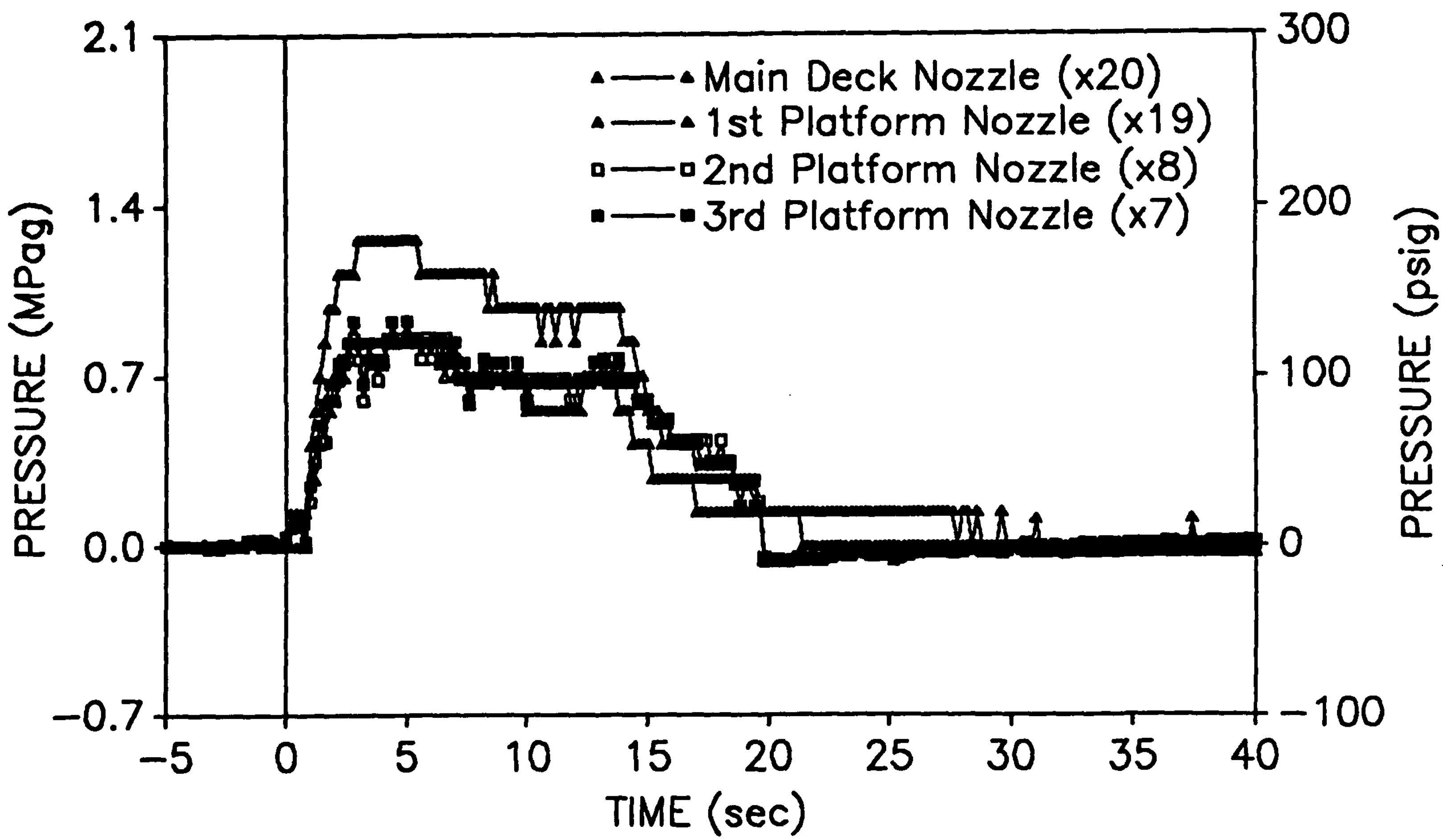

Fig. 68 — Representative nozzle pressures during Halon 1301 discharge

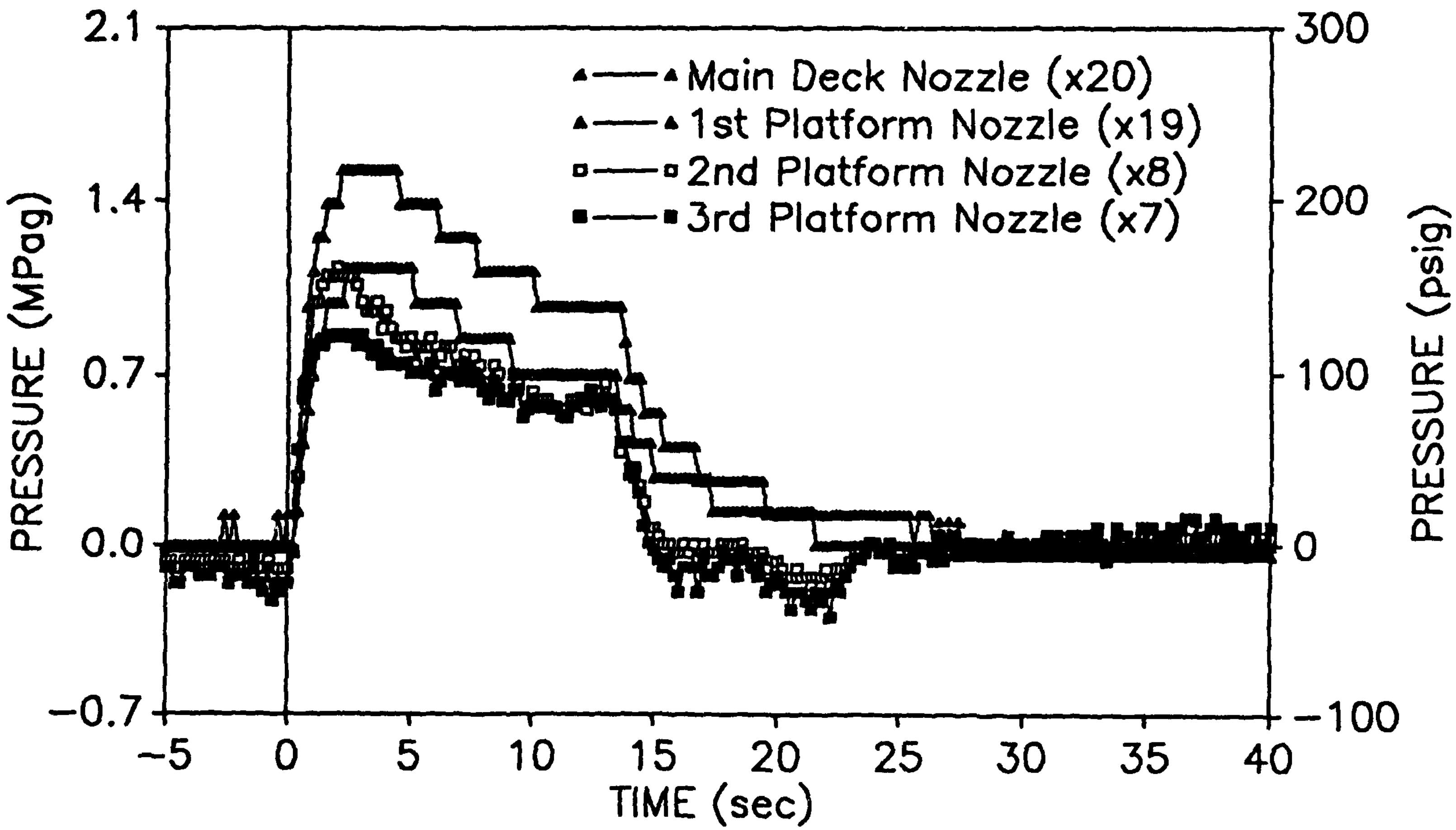

Fig. 69 — Representative nozzle pressures during sulfur hexafluoride discharge

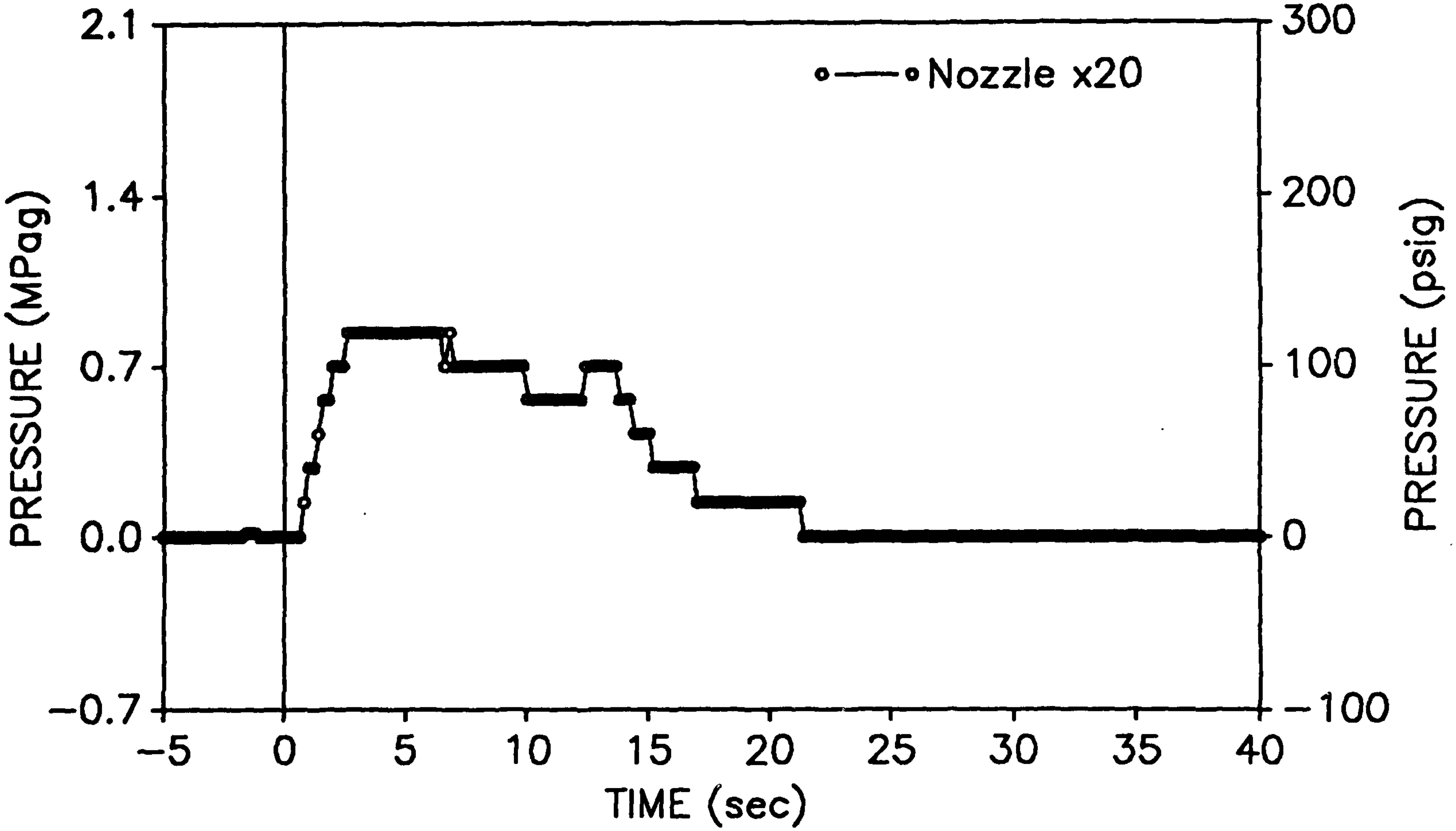

Fig. 70 — Pressure at main deck nozzles during Halon 1301 discharge

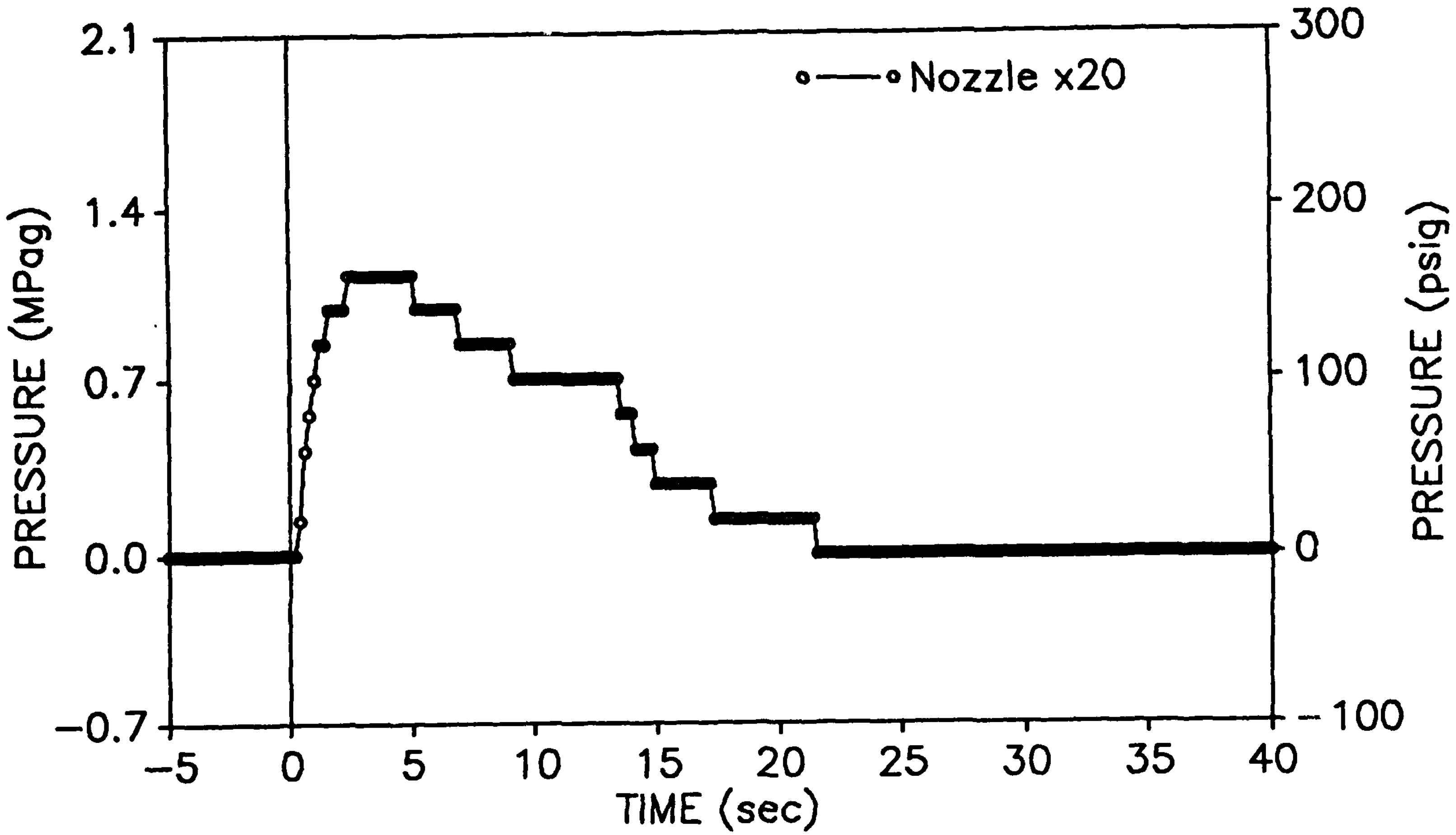

Fig. 71 – Pressure at main deck nozzles during sulfur hexafluoride discharge

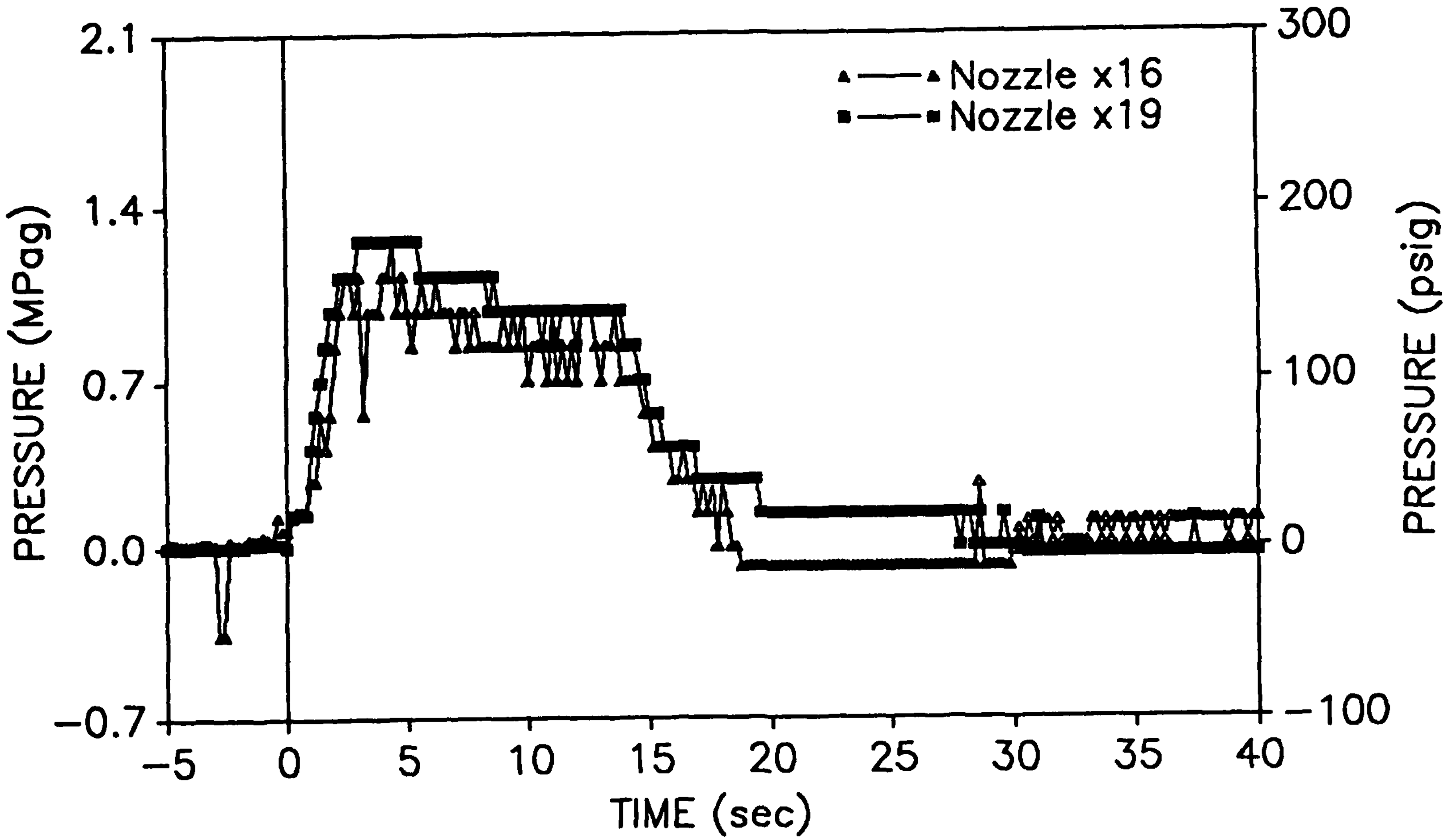

Fig. 72 — Pressure at 1st platform nozzles during Halon 1301 discharge

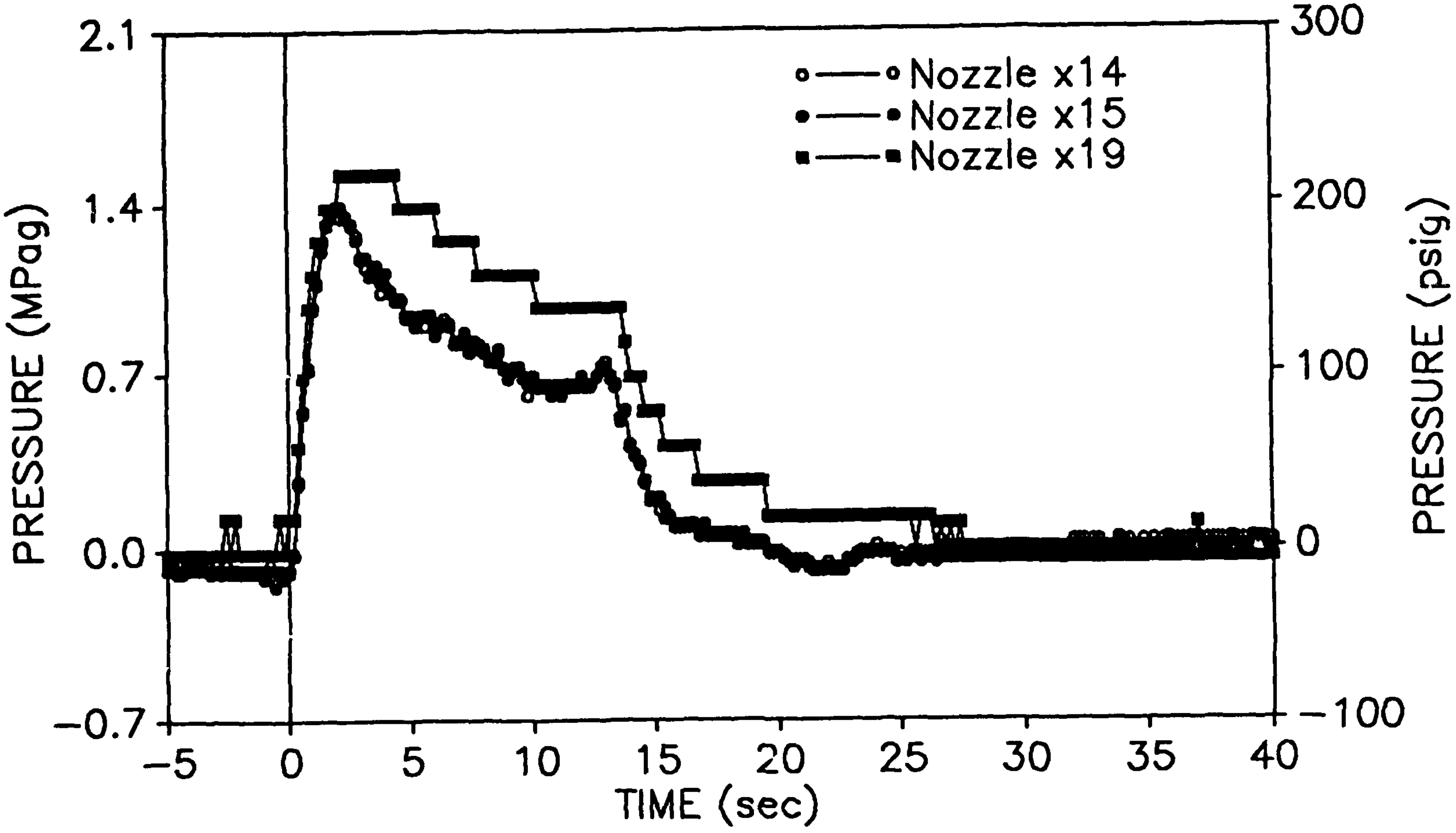

Fig. 73 — Pressure at 1st platform nozzles during sulfur hexafluoride discharge

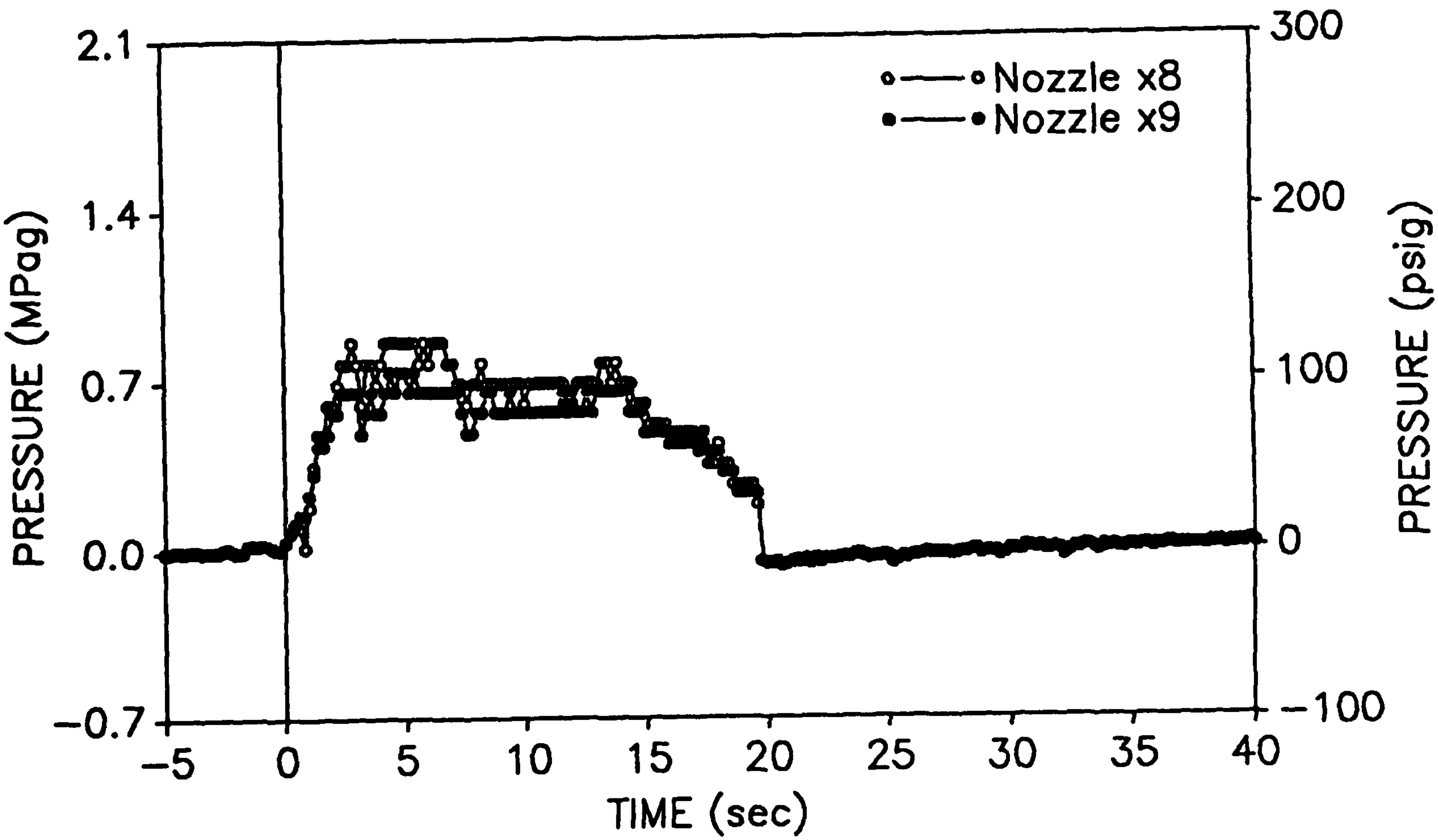

Fig. 74 – Pressure at 2nd platform nozzles during Halon 1301 discharge

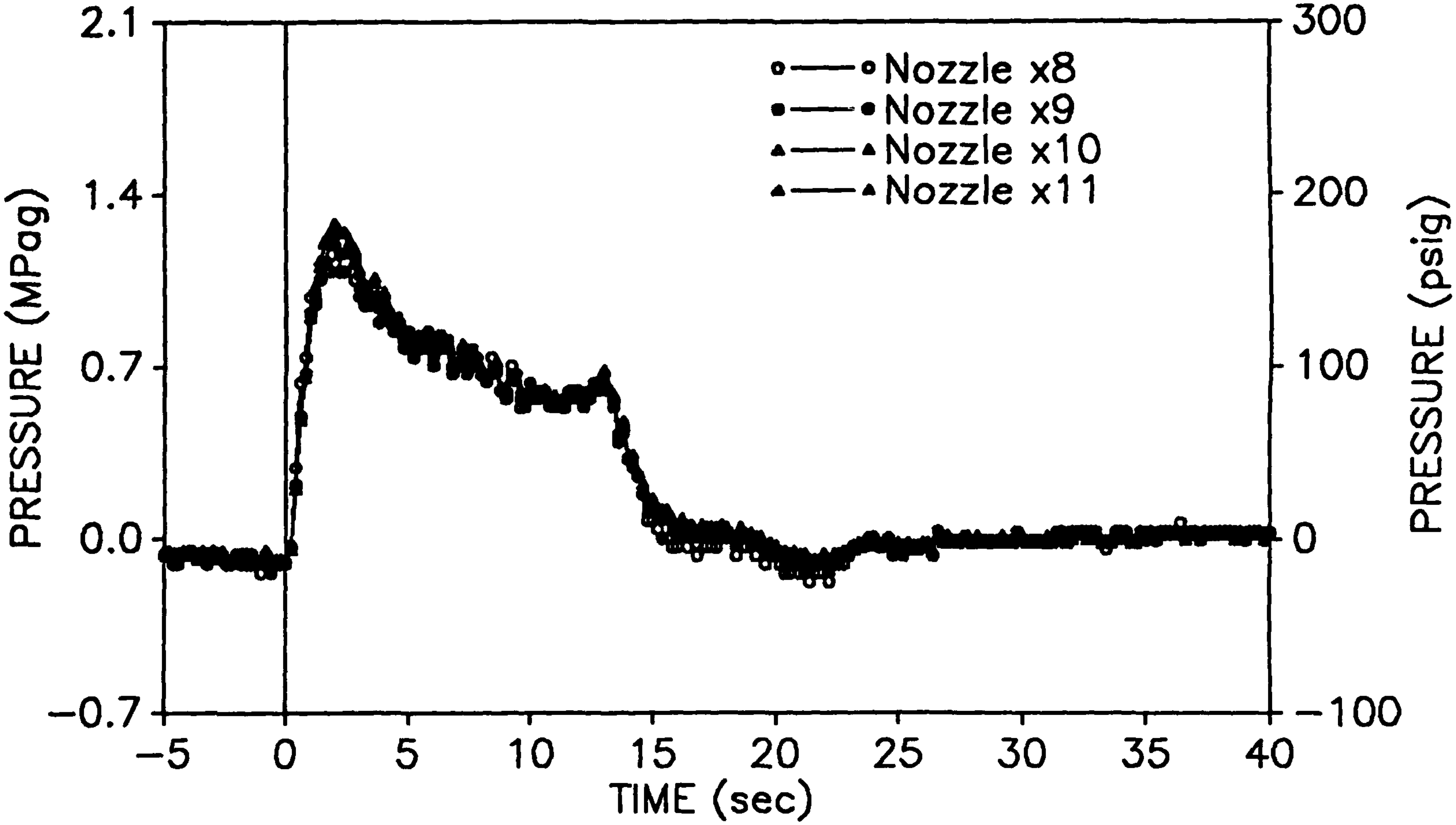

Fig. 75 – Pressure at 2nd platform nozzles during sulfur hexafluoride discharge

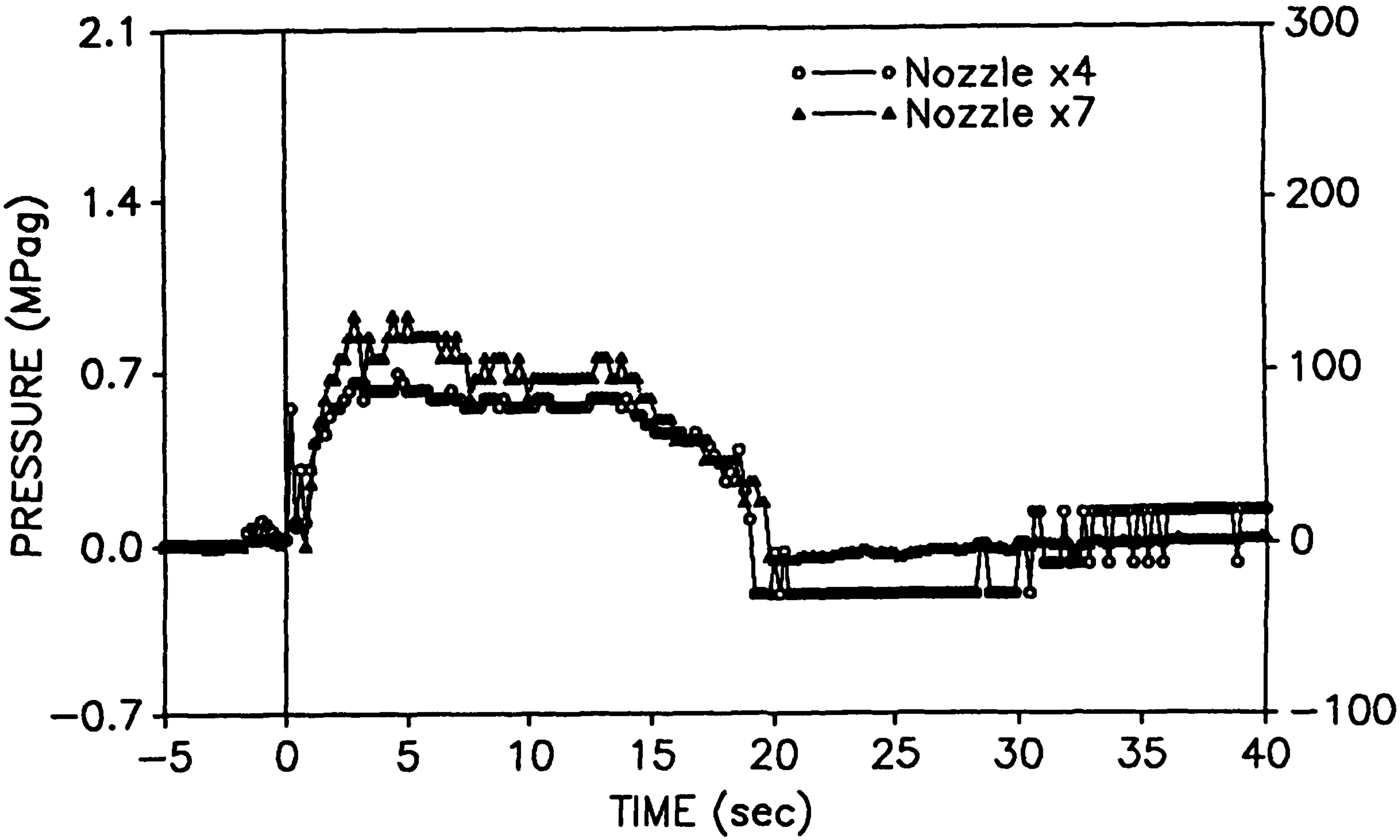

Fig. 76 – Pressure at 3rd platform nozzles during Halon 1301 discharge

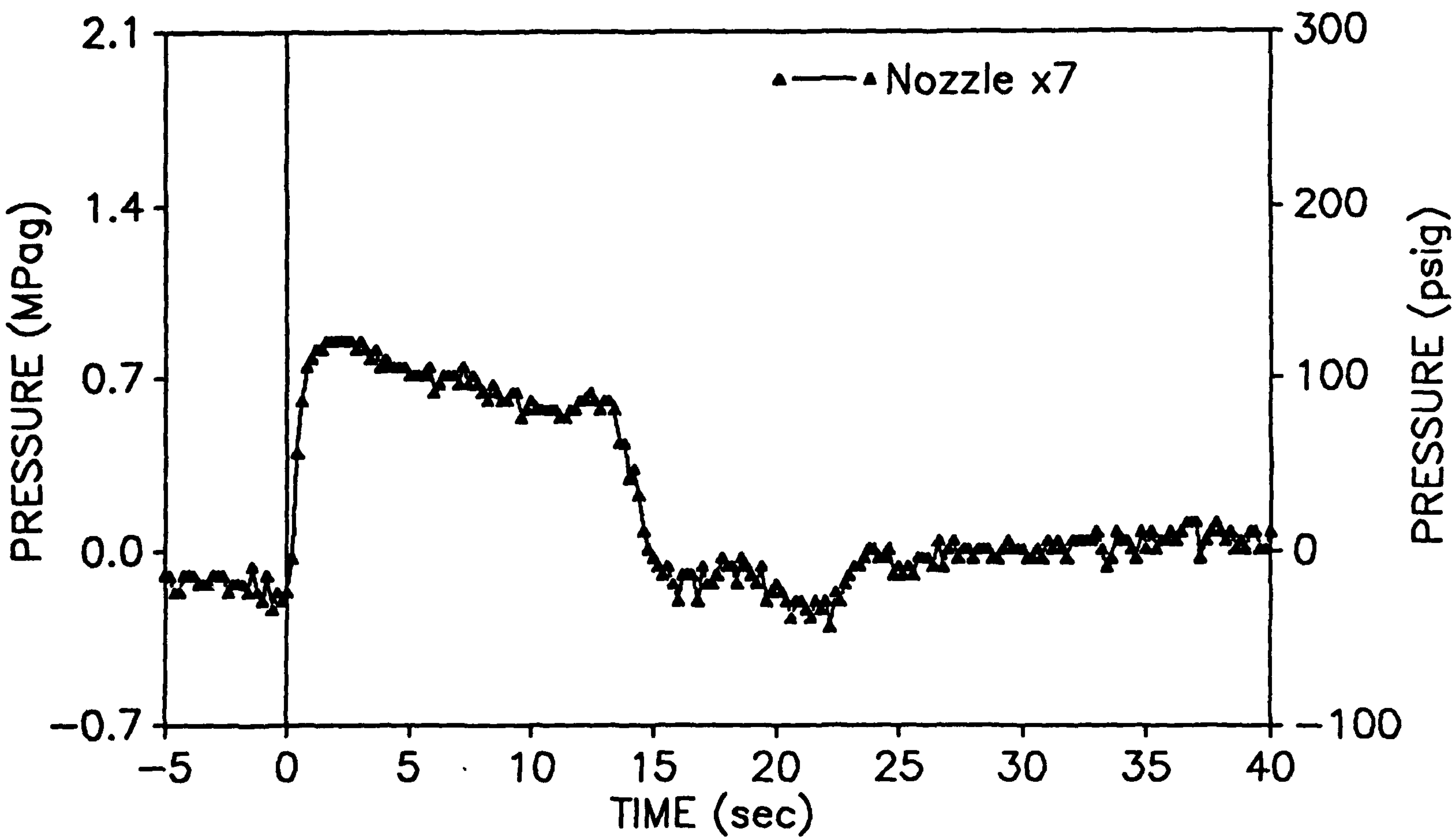

Fig. 77 – Pressure at 3rd platform nozzles during sulfur hexafluoride discharge

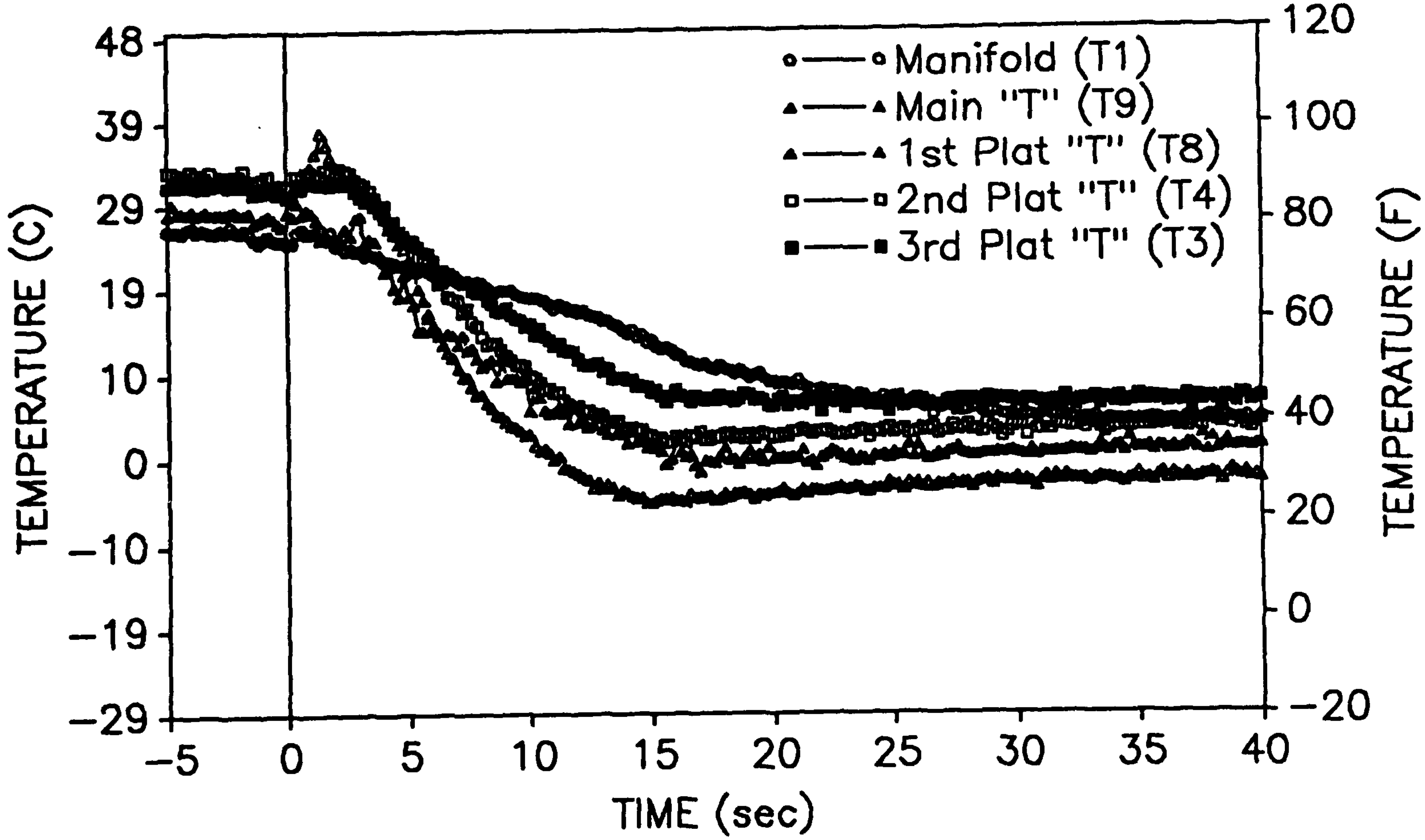

Fig. 78 — Temperature of exterior pipe walls at representative locations during Halon 1301 discharge

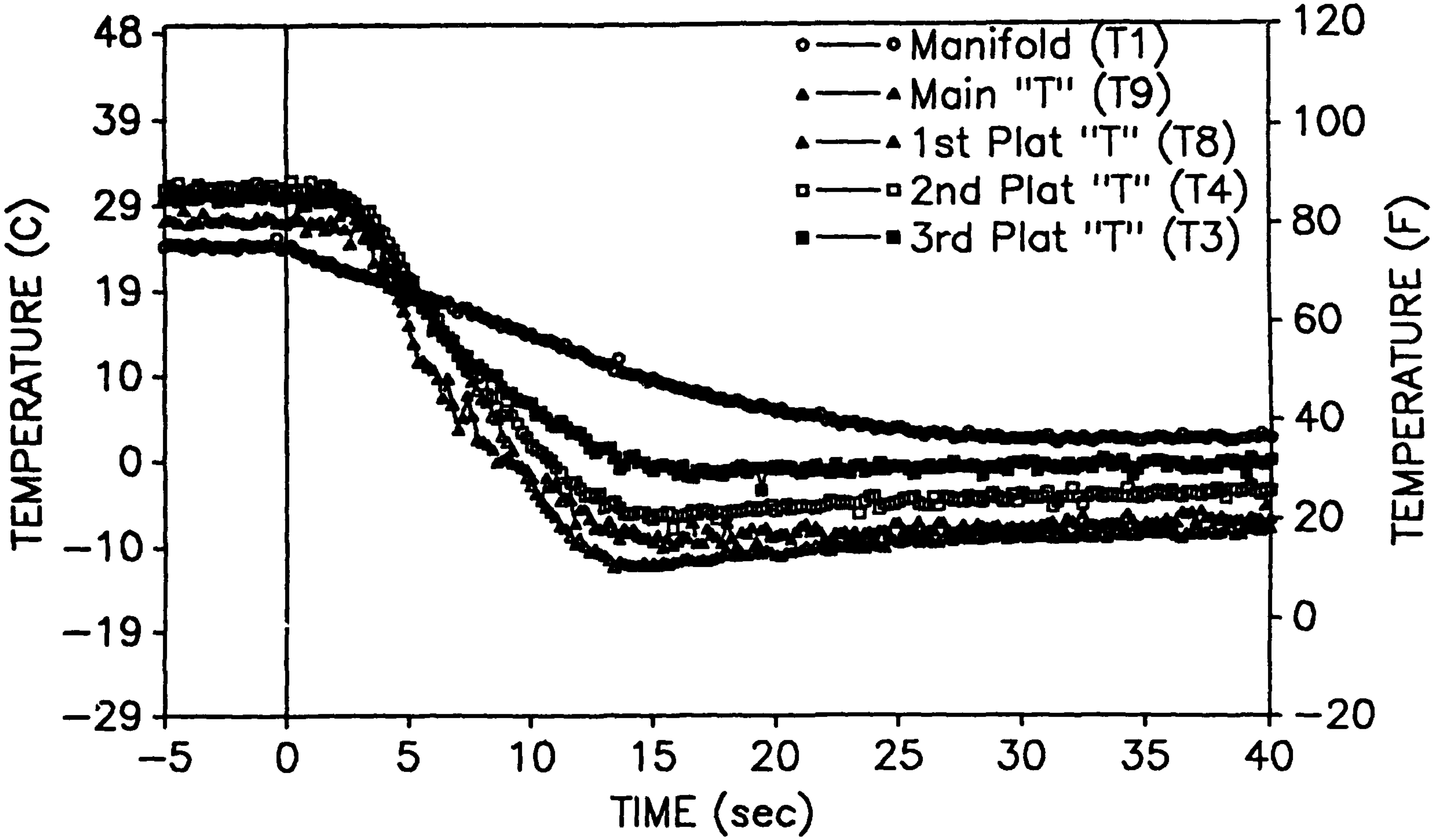

Fig. 79 — Temperature of exterior pipe walls at representative locations during sulfur hexafluoride discharge

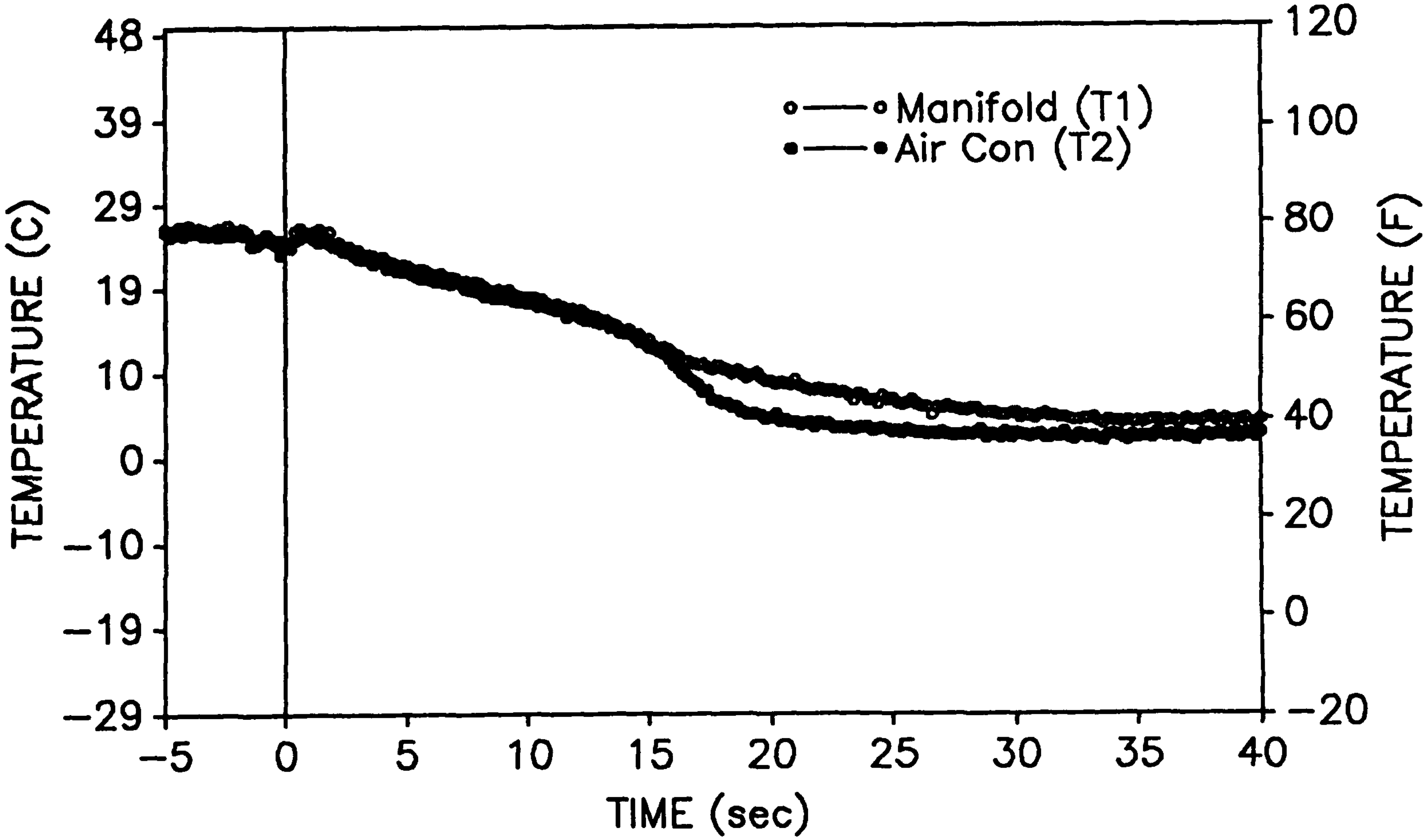

Fig. 80 – Temperature of exterior pipe walls in halon room during Halon 1301 discharge

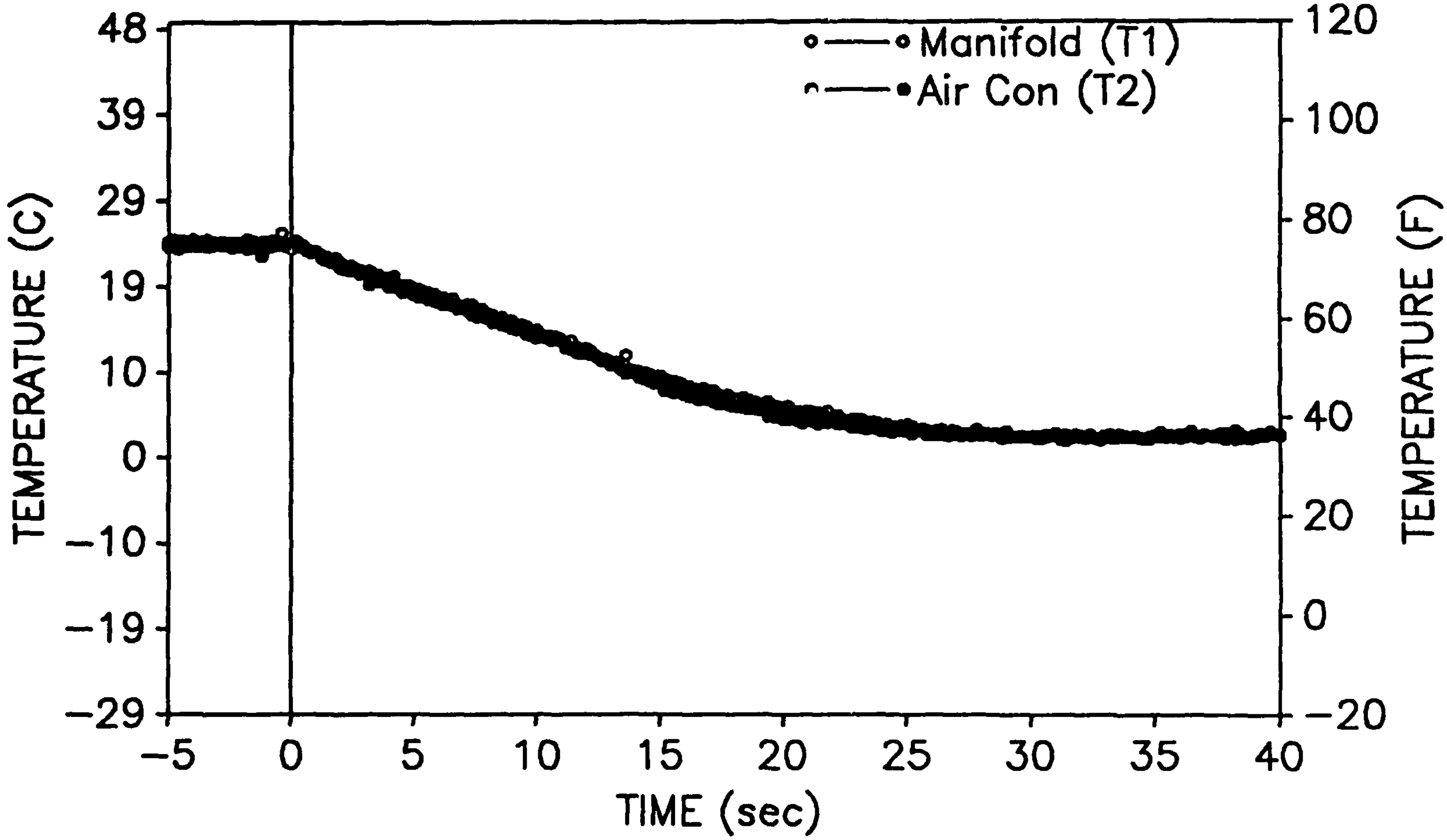

Fig. 81 – Temperature of exterior pipe walls in halon room during sulfur hexafluoride discharge

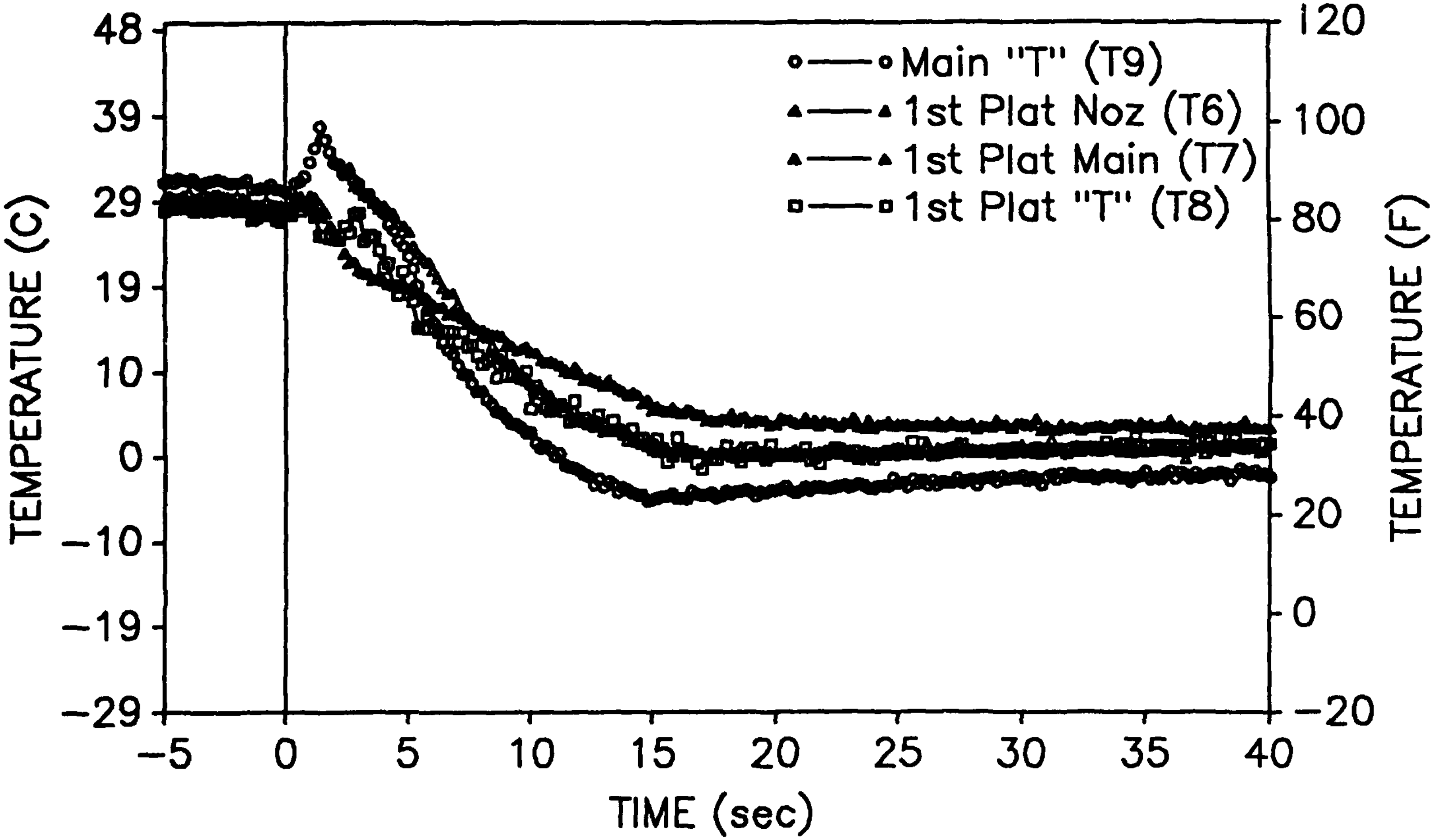

Fig. 82 – Temperature of exterior pipe walls on main deck or 1st platform during Halon 1301 discharge

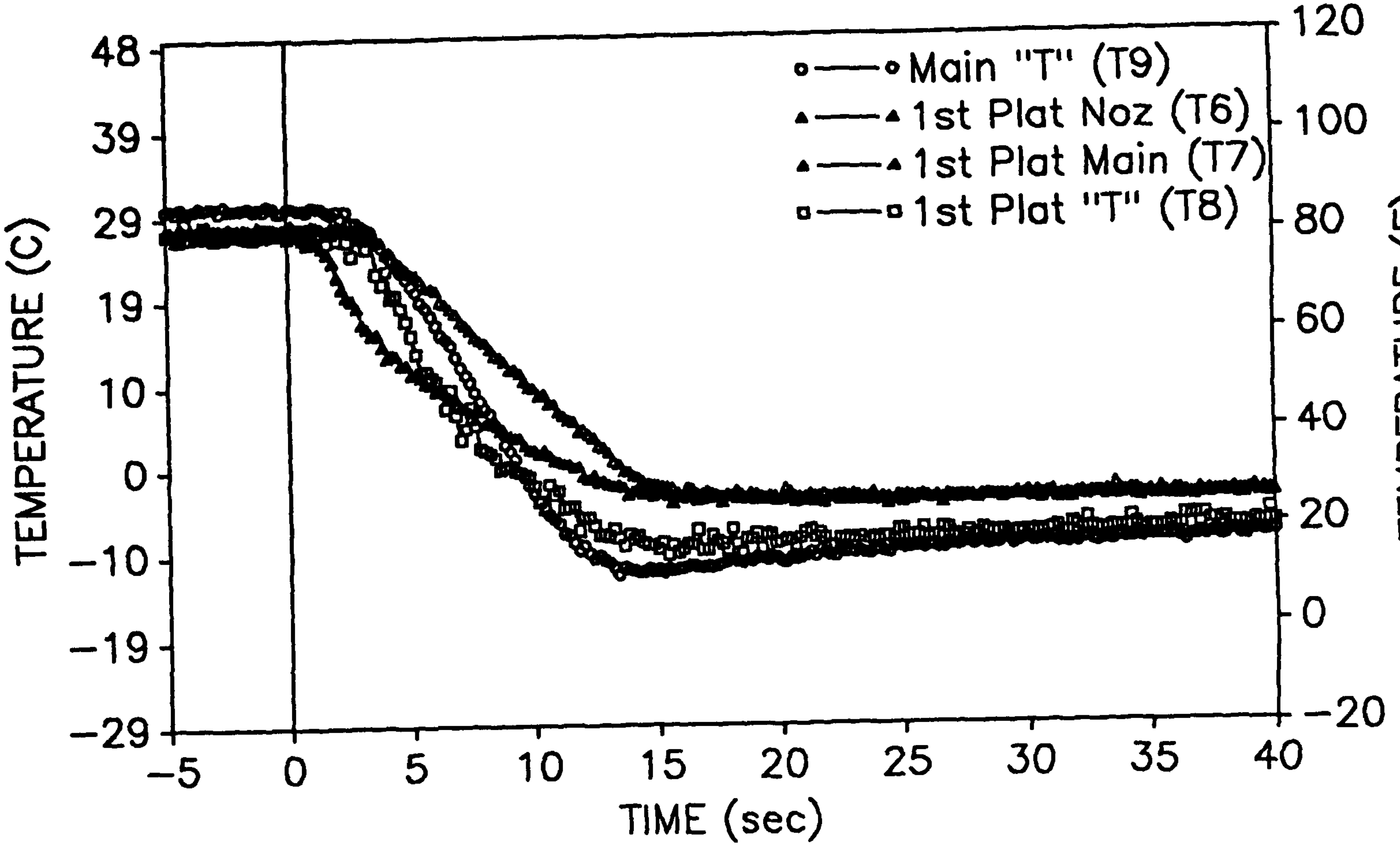

Fig. 83 — Temperature of exterior pipe walls on main deck or 1st platform during sulfur hexafluoride discharge

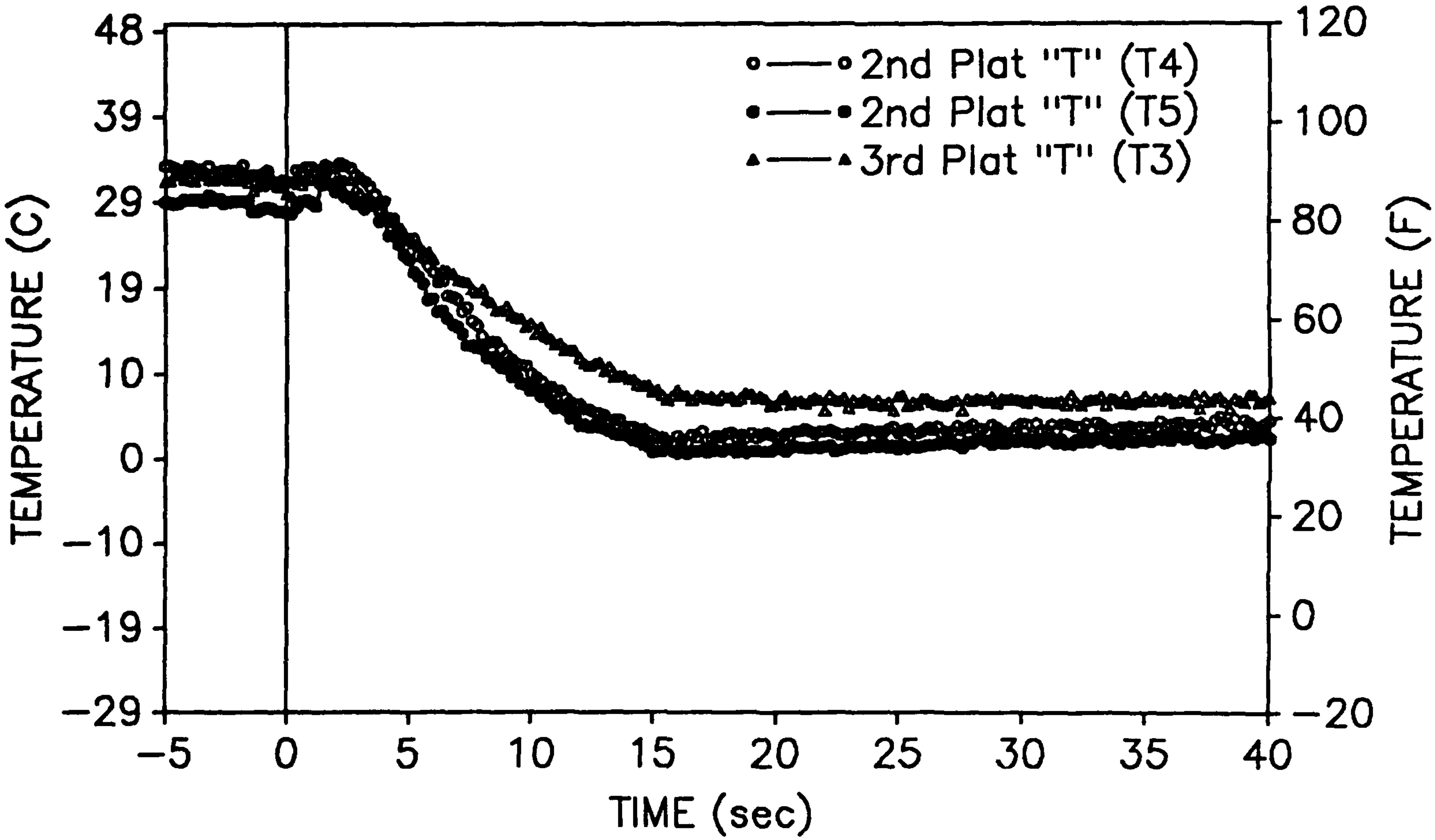

Fig. 84 — Temperature of exterior pipe walls on the 2nd and 3rd platforms during Halon 1301 discharge

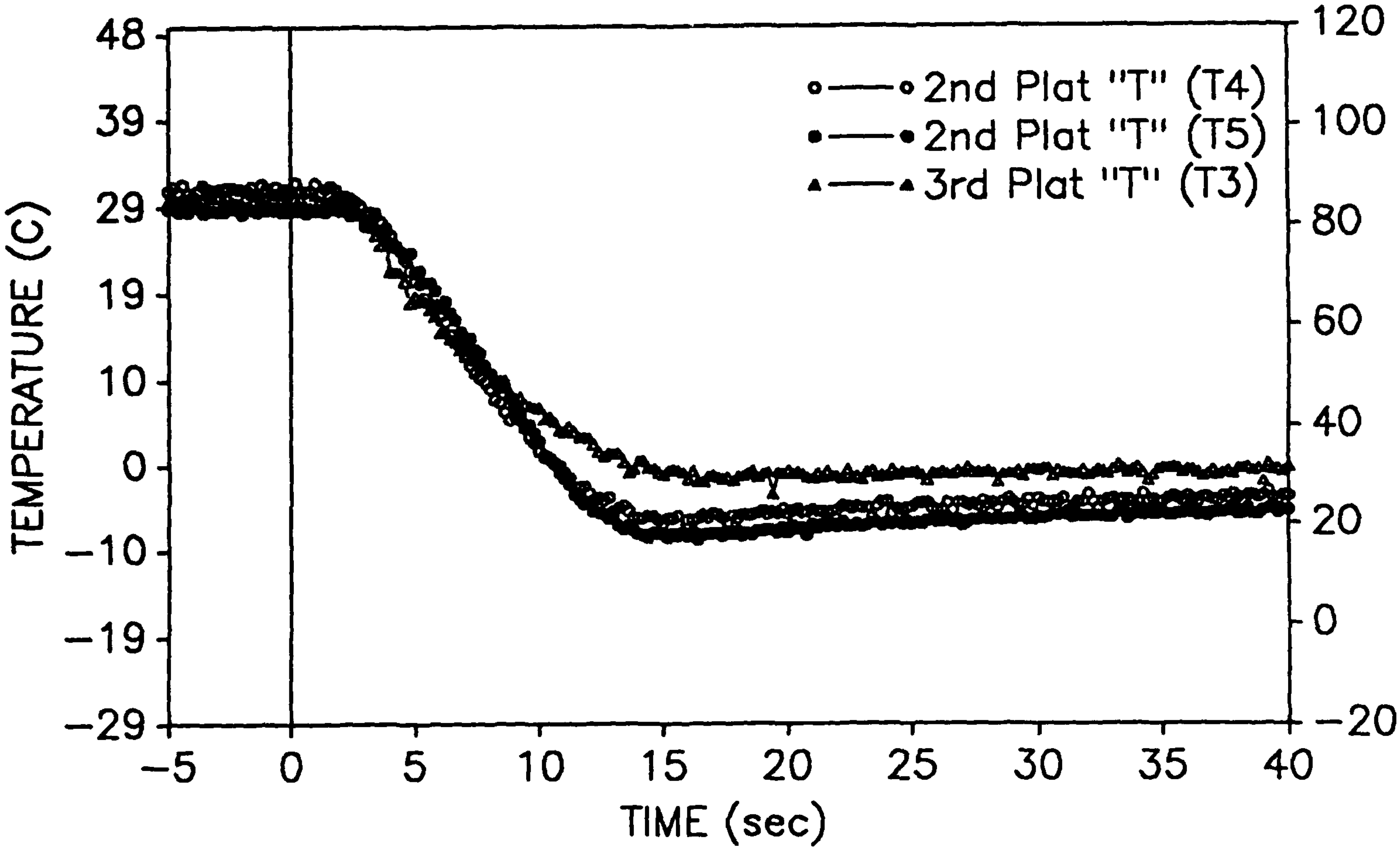

Fig. 85 – Temperature of exterior pipe walls on the 2nd and 3rd platforms during sulfur hexafluoride discharge

APPENDIX B

APPENDIX B

Ventilation System Effects

The ventilation system of engine room No. 2 was monitored during these tests to evaluate what effects it had on the halon 1301 concentration in the engine room. The ventilation system is shut down upon system actuation by a pneumatic control switch. This gives the ventilation system the one minute duration of the time delay to shut down before the actual discharge of Halon 1301. Figure 80 shows the velocity of the flow out of one of the two 76 cm (30 in.) ID ventilation exhaust ducts.

This flow out of the exhaust duct has four distinct regions. The first is the pre-actuation flow where the ventilation system is in its normal operating mode. The second region is the coast down of the ventilation fans. This coast down is approximately 85 % complete when the actual discharge occurs. The third region is discharge induced flow. The discharge into the engine room causes a temporary over pressure in the space that results in a puff out of the space. In general a second puff into the space is expected due to the cooling effect of the agent discharged, but this is not seen in figure 80. This could be caused by a dampening of this pulse caused by the fans or just the large volume of the space. The last region is the wind induced flow region. This region exists because this

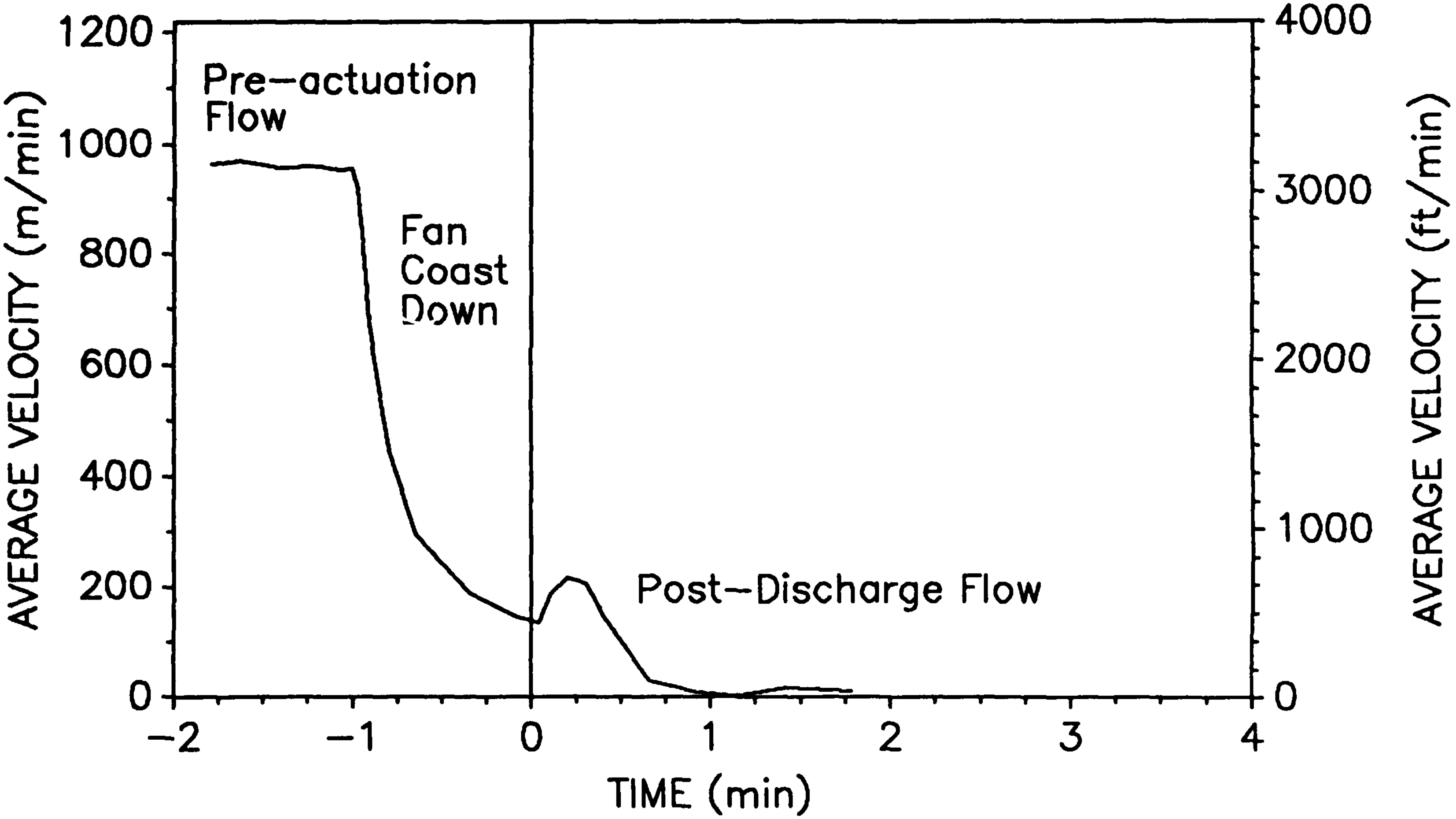

Fig. 86 – Velocity of flow out of ventillation exhaust duct

space is not isolated from the weather after discharge. There was essentially no wind during these tests and therefore essentially no wind induced flow.

The effects of the ventilation system on the maintenance of Halon 1301 in the engine room was insignificant in these tests.

The ventilation system was able to clear the engine room of either Halon 1301 or SF_6 in less than 15 minutes after the restart of the fans. This can be seen in the concentration traces given in Appendix A.